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A Human Operator Simulator Model of the NASA Terminal Configured Vehicle (TCV)

Floyd A. Glenn III and Stephanie M. Doane

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Prepared for
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National Aeronautics
and Space Administration

**Scientific and Technical
Information Branch**

1981

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SUMMARY

The Human Operator Simulator (HOS) has been used as a basis for constructing a simulation of the performance of an aircraft pilot and aircraft that he controls. The situations that were simulated were taken from a study of pilot eye scan patterns reported by Harris and Mixon (1979). The study was concerned with issues of pilot performance in an innovative pilot crewstation that employs CRT displays for attitude information and horizontal situation. Two control modes were employed in the simulations; in one mode, Velocity Control Wheel Steering (VCWS), the pilot manually directs all changes in aircraft flight path and track angles and the autopilot maintains these course parameters between pilot actions; in the other control mode, 3D-Auto, the autopilot controls all attitudes and course parameters to navigate a predefined, three-dimensional flight path. Both control modes were employed for separate simulations of a curved approach to landing while only the VCWS mode was employed for a straight-in approach to landing. The joint objectives of this study are the demonstration of the feasibility of such a simulation of pilot/aircraft performance using HOS and the achievement of insight into the experimental results reported by Harris and Mixon. Simulation results are discussed with respect to these objectives.

1. INTRODUCTION

Through a series of experiments conducted at NASA Langley Research Center, a great deal has been learned about the visual aspects of aircraft pilot behavior. Using an unobtrusive oculometer system, pilot's eye movements and fixations have been monitored in a variety of crew stations, display formats, control modes, and scenario conditions. Data from these studies has been used to characterize the manner in which equipment and situational factors influence the pilot's behavior and performance. These results have also supported inferences concerning the characteristics of the monitoring and control procedures used by the pilot to accomplish his tasks.

In support of this line of research, the Human Operator Simulator (HOS) has been used to simulate experiments reported by Harris and Mixon (1979). The crew station used in the experiments was a fixed base simulator for the NASA Terminal Configured Vehicle (TCV). Primary instrumentation included Cathode Ray Tube (CRT) displays of aircraft attitude information and horizontal situation. The objective of these experiments was to evaluate the effects of the new display and control concepts of the TCV system on pilot scan patterns which has previously been studied in context of conventional pilot station instruments and procedures.

The motivation of this HOS replication of the Harris and Mixon experiments has been to demonstrate the suitability of HOS for this type of application and to construct a foundation for further simulations of pilot oculometer studies. The longer term objective of this effort is to develop a vehicle for integrating and extrapolating knowledge gained from a wide variety of experimental studies of pilot behavior. Such a vehicle could be realized by iteratively developing a HOS simulation with pilot monitoring and control procedures gleaned from and validated against experimental data.

The first stage of such an iterative development consists of the construction and evaluation of an initial baseline simulation. The simulation documented in the report provides this baseline. Subsequent efforts will improve the fidelity of the simulation through the modification of pilot procedures and simulation parameters to increase the correspondence between simulation and experimental results. Refinements to the simulation will accumulate as modifications are suggested by experimental data and as new experiments are generated through study of the simulated pilot procedures. This iterative process of revision and evaluation should quickly converge to a simulation that will provide useful insight into questions regarding crew roles, procedures, and performance. Such insights will aid in the development of improved display concepts and procedure definitions. Eventually, as simulation fidelity is further refined, it may become justifiable to substitute simulation for man-in-the-loop experimentation in the initial evaluation of new crewstation concepts.

The remainder of this report describes the initial implementation of a HOS simulation of pilot and system performance in the context established by Harris and Mixon. Although a primary measure of simulation success is correspondence with oculometer data, it is important to recognize that a prior, non-trivial objective for the simulation is realistic aircraft control. At a minimum, the simulated pilot must be able to perform the mission that the real pilots perform. In the case of the Harris and Mixon experiments, this means that the simulated pilot must be able to accomplish a successful approach to landing up to the point of touchdown. In order to achieve acceptable pilot control in the simulation, it is necessary to develop adequate control procedures, appropriate parameter values, and satisfactory models of aircraft and autopilot dynamics. After the simulation of pilot control of the aircraft is deemed acceptable, refinements of procedures and parameters along lines suggested by experimental research results can begin.

The requirement for the use of the International System of Units (SI) as the primary unit of measure has been waived for this report. A conversion table is provided in Appendix C.

2. OVERVIEW OF HOS

HOS is described at length in several reports (Strieb, Glenn, and Wherry, 1978; Strieb, 1979; Glenn and Wherry, 1979) so only a general overview will be presented here with emphasis on details critical to the TCV simulation. HOS is a general simulation program that is designed to be used to study the performance of a trained human operator and the hardware/software system that he uses to accomplish a well-defined mission. It provides the framework for implementing a simulation in the form of a simulation language, a set of basic human performance models, an executive program that controls the simulation, and a collection of analysis programs for analyzing simulation results. HOS simulations are written primarily in the Human Operator Procedures (HOPROC) language with supporting calculations coded in a variant of FORTRAN. The same HOPROC language is used to describe the hardware/software dynamics of the system being operated and the monitoring and controlling procedures employed by the human operator. For operator and system processes that require substantial mathematical calculations (e.g., mental computations and decisions made by the operator and physical characteristics of the hardware), the HOS variant of FORTRAN is used to describe Operator Functions and Hardware Functions. Executions of Operator Functions are directed by the Operator Procedures and execution of Hardware Functions are directed by the Hardware Procedures. Ths HOS Assembler and Loader (HAL) is used to compile the HOPROC and FORTRAN inputs into a compact form that can be executed by the HOS executive. Although HOS generates a readable record of simulation results in the form of a detailed time-log of simulation events, it is generally valuable to use the Human Operator Data Analyzer/Collator (HODAC) to generate statistical summaries of the HOS outputs. Figure 1 presents a flow diagram for implementation of HOS simulations.

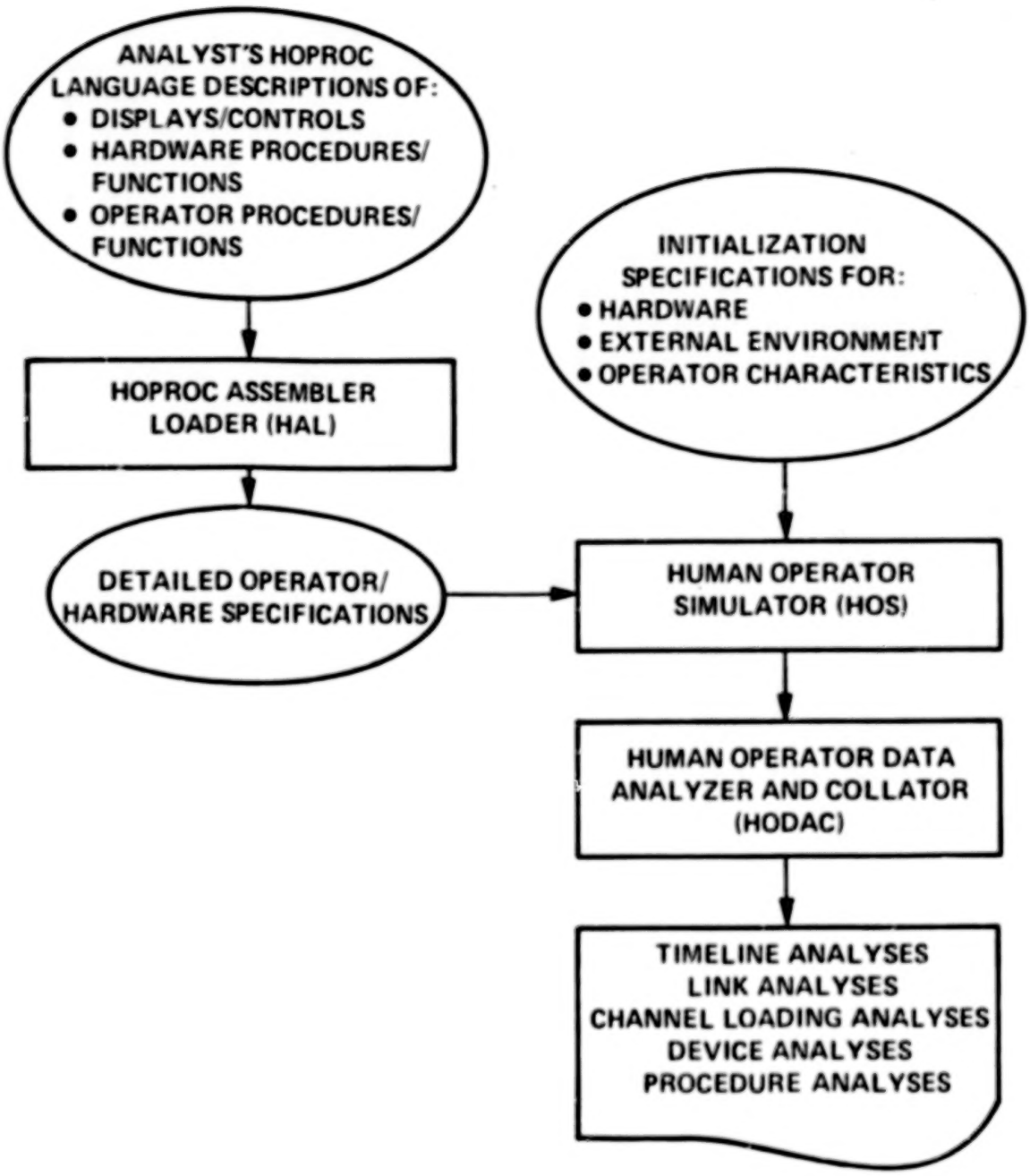


Figure 1. HOS Program Flow

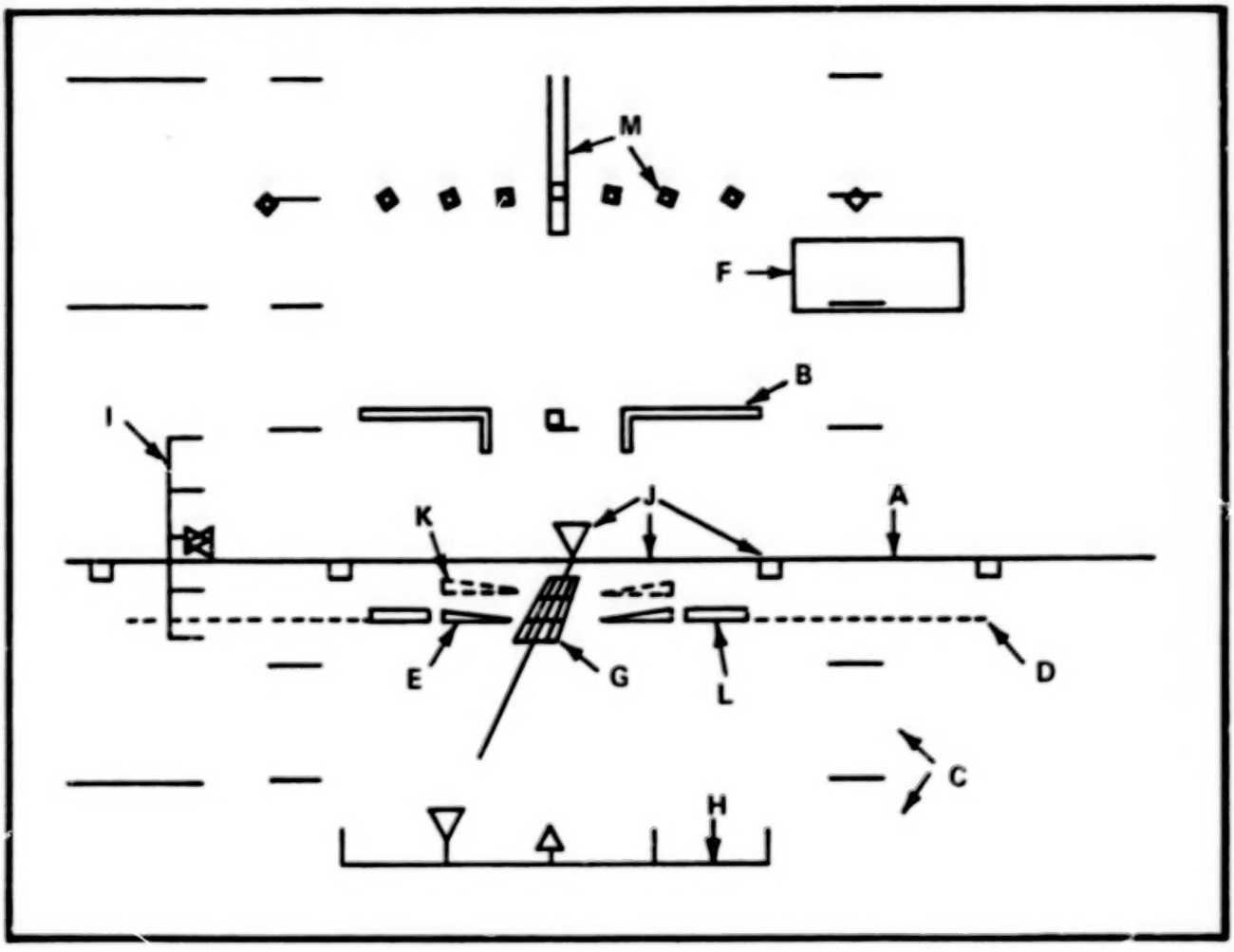
A key characteristic of HOS that enables the development of realistic simulations of human performance is the procedure multiplexing model. A HOS Operator Procedure does not "call" another procedure the same way a FORTRAN program calls a subroutine. Rather, it places the procedure to be executed on an "active procedures list". Whenever the simulated operator (assumed to be a single-channel serial processor) is interrupted in executing a procedure, the multiplexing model is invoked to select a new procedure from the active procedure list. While the HOS operator can execute only one procedure at a time, individual actions can occur simultaneously if they do not require the same physical resources; virtual parallel processing can be achieved through rapid switching between procedures. Procedural selection takes into account the types of the procedures on the active procedure list (there are special procedures for enabling, adjusting, and disabling devices), the initial criticality for each procedure as supplied by the analyst, the amount of time elapsed since the procedure was last executed, and, for procedures that adjust or monitor devices, how close the value of the device is to its desired value. The multiplexing algorithm has been designed to give an intuitively reasonable weight to each of these factors.

The HOS procedure multiplexing model is particularly important in situations in which the task of the human operator is principally to monitor a relatively automatic system. For example, in flying an aircraft under autopilot control, the job of the pilot is mainly to check continually that the autopilot is functioning properly. In order for HOS to simulate how the pilot monitors the autopilot, HOPROC procedures describe the general logic of the checks on the equipment, Operator Functions perform the calculations and decisions involved in the checks, and the multiplexor determines when each monitoring check is executed.

3. TCV PILOT STATION INSTRUMENTS

The instruments of primary importance in the HOS-TCV simulation are the Electronic Attitude Direction Indicator (EADI) shown in Figure 2 and the Electronic Horizontal Situation Indicator (EHSI) shown in Figure 3. While the Navigational Control Display Unit (NCDU) is an important component of the TCV vehicle, it was not utilized by Harris and Mixon (1979) in their study, and consequently is not simulated here. The following description of EADI and EHSI features will deal principally with those features employed in the Harris and Mixon study since only those features were incorporated in the HOS simulation.

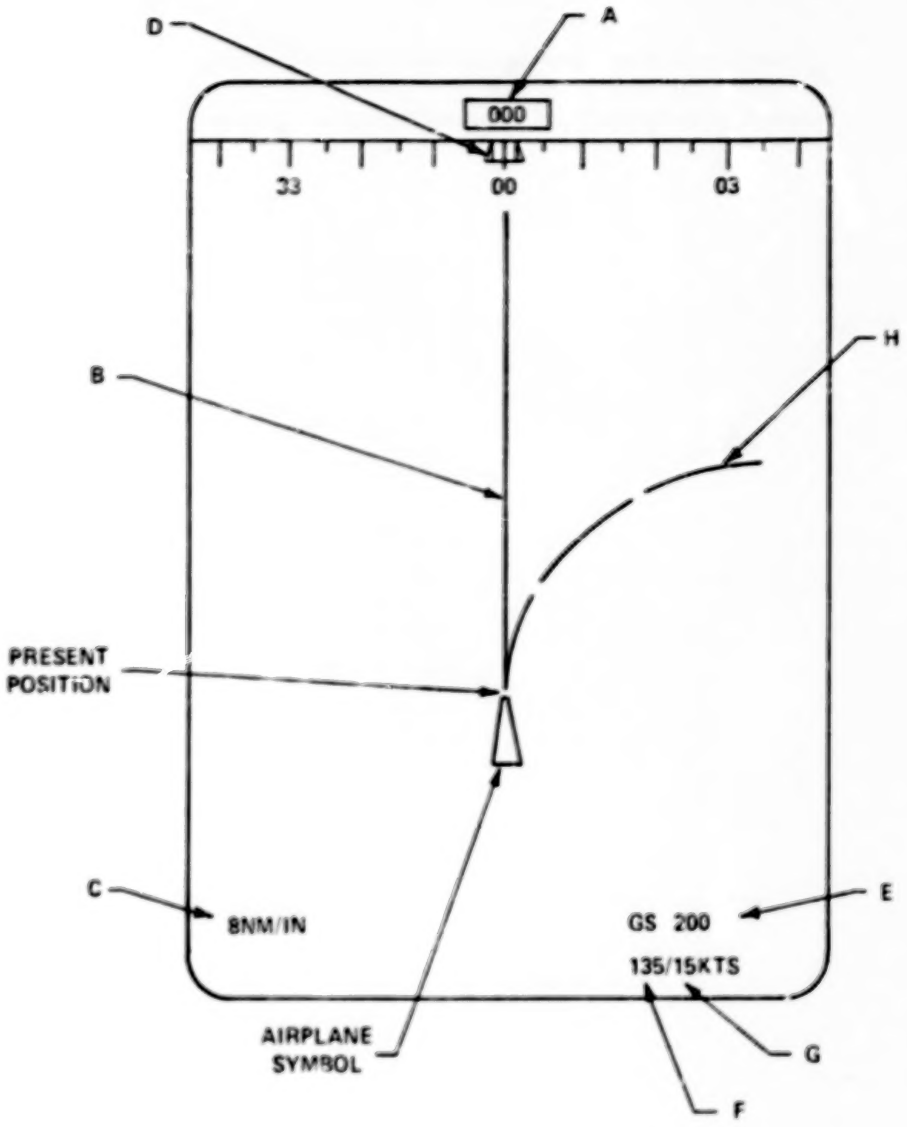
The EADI conveys attitude, flight path angle, and path error information. Graphically displayed are the aircraft symbol, nose reference symbol, and the perspective runway. The aircraft symbol and nose reference symbol are biased 5° upward to unclutter the display around the horizon region during level flight. Horizontal lines extending across the display are used to represent the horizon line and the pitch reference line. A track scale and pointer are located along the horizon line. Also displayed are the bank angle, glideslope, and localizer scales. The bank angle scale is calibrated in 10° demarcations and displays the bank angle assumed in a turn. The localizer scale displays lateral deviation from the desired path. In ILS mode, each dot on the localizer scale corresponds to a 1° lateral deviation from the prescribed path relative to the localizer beacon. The localizer also displays lateral errors in the MLS mode when a complete flight path programmed in the flight computer is controlling the aircraft through the autopilot (as in the case of the 3D-AUTO control mode simulated in the present study). In that case, each localizer dot corresponds to a lateral deviation of 500 feet. The glideslope scale displays vertical deviation from the desired path. In the ILS mode, each dot on the glideslope scale corresponds to a vertical deviation of .35° from the prescribed



LEGEND (SYMBOL NAME FOLLOWED BY HOPROC VARIABLE NAME IN PARENTHESES):

A. HORIZON LINE (HORIZON)
B. AIRPLANE SYMBOL (AIRCRAFT-SYMBOL)
C. PITCH SCALE (AIRCRAFT-PITCH)
D. PITCH REFERENCE LINE (PITCH-REF-LINE)
E. FLIGHT PATH ANGLE (GAMMA-WEDGES)
F. RADAR ALTITUDE (RADIO-ALTITUDE)
G. RUNWAY PERSPECTIVE AND EXTENDED CENTERLINE (RUNWAY-LINE-INTRCPT) (RUNWAY-LINE-ANGLE)
H. LOCALIZER SCALE AND POINTER (LOCALIZER)
I. GLIDESLOPE SCALE AND POINTER (GLIDE-SLOPE)
J. TRACK ANGLE SCALE AND POINTER (TRACK-POINTER)
K. FLIGHT PATH ANGLE REFERENCE (COMMAND-GAMMA)
L. FLIGHT PATH ACCELERATION BARS (FLIGHT-PATH-ACC)
M. BANK ANGLE SCALE AND POINTER (ROLL-INDICATOR)

Figure 2. TCV Electronic Attitude Direction Indicator (EADI)



LEGEND (SYMBOL NAME FOLLOWED BY HOPROC VARIABLE NAME IN PARENTHESES)

A. TRACK BOX (TRACK-BOX)
B. STRAIGHT TREND VECTOR (STRAIGHT-VECTOR)
C. MAP SCALE (MAP-SCALE)
D. DESIRED TRACK BUG (TRACK-BUG)
E. GROUND SPEED (GROUND-SPEED)
F. WIND DIRECTION (WIND-DIRECTION)
G. WIND VELOCITY (WIND-VELOCITY)
H. CURVED TREND VECTOR (CURVED-VECTOR-RADIUS)

Figure 3. TCV Electronic Horizontal Situation Indicator (EHSI)

flight path. When flying under MLS with a programmed flight path (i.e., 3D-AUTO mode), each glideslope dot corresponds to a vertical error of 100 feet. Radio altitude is displayed on the EADI only at altitudes of less than 2,500 feet. The solid wedges (the gamma wedges) indicate the flight path angle. The displacement between the airplane symbol and the gamma wedges represents the aircraft's angle of attack. The dashed wedges are the command gamma symbol. In Velocity Control Wheel Steering (VCWS) control mode (described later), the pilot can set the reference wedges at any desired flight path angle by applying a longitudinal force on the Brolly handles. The autopilot system will then alter the actual flight path angle to the indicated value. The aircraft symbol remains stationary on the CRT while all other symbols change position. When the aircraft descends to the decision-height altitude (which is entered by the pilot via the EADI mode control panel) the EADI so indicates by flashing the nose reference symbol.

The EHSI conveys lateral path information. In the HOS-TCV simulation, it is used in track-up mode. In this mode, all displayed positions are continually slued so that the aircraft heading is indicated toward the top center of the screen. Map scale, which is adjustable between 1 and 32 nautical miles per inch, is set between the values of 1 and 4 in the simulation so that all remaining waypoints are displayed. The trackbox at the top of the EHSI indicates magnetic track angle. The straight trend vector indicates the path the plane will follow if the current track angle is maintained. Also represented in the simulation is the curved trend vector. This feature predicts the aircraft's position 30, 60, and 90 seconds into the future, assuming the current rate of turn and ground speed are maintained. Heavy use of the curved trend vector occurs when the pilot executes a turn under VCWS control. As the plane reaches the waypoint where the turn is to begin, the pilot rolls the aircraft (using the Brolly handles), until the curved trend vector intersects the next waypoint. At this time, the pilot releases the Brolly handles. The aircraft symbol represents the present aircraft position. The symbol remains stationary on the CRT and all other displayed positions are replotted relative to the aircraft as the aircraft moves.

The AGCS Panel, illustrated in Figure 4, allows the pilot to select various combinations and levels of automatic flight assistance. There are three major levels of assistance -- control wheel steering, select hold, and automatic path modes. Control wheel steering can be manifested in two modes, Velocity Control Wheel Steering (VCWS) and Attitude Control Wheel Steering (ACWS) which offer the pilot partially automated control options. Under both of these modes, the pilot can control aircraft attitude by manipulating the Brolly handles as under standard manual control, but when he stops applying any force to the handles, the autopilot serves to maintain the aircraft velocity vector or attitude occurring at that time. In the vertical plane, VCWS holds the flight path angle (gamma or angle of aircraft climb or dive) while ACWS holds the aircraft pitch attitude established by the pilot. In the horizontal plane, the main difference between VCWS and ACWS is that, when the bank angle is less than 5°, at the time of force release, ACWS control maintains that bank angle, while VCWS control instead maintains the instantaneous track angle. Only the VCWS mode is employed in the present study. The pilot can also specify numerical values of flight parameters to be maintained by the autopilot system through the select hold control options. Four flight parameters can be commanded in this manner through the AGCS Panel -- airspeed, altitude, flight path angle, and track angle. An example of a select hold mode is the calibrated airspeed mode. This mode allows the pilot to control the autothrottle system independent of the navigation computer flight plan. As with all the digital displays on the AGCS, when the switchlight is off, the readout provides the actual airspeed. The pilot can then preselect a particular airspeed by rotating the CAS-ENG knob. When the mode is engaged, the readout shows the desired rather than the actual airspeed. When the AUTO mode is engaged, it automatically selects flight path angle select (FPA-SEL) and track angle select (TKA-SEL). These two modes allow the pilot to "dial in" flight path angle and track angle in a manner similar to the calibrated airspeed.

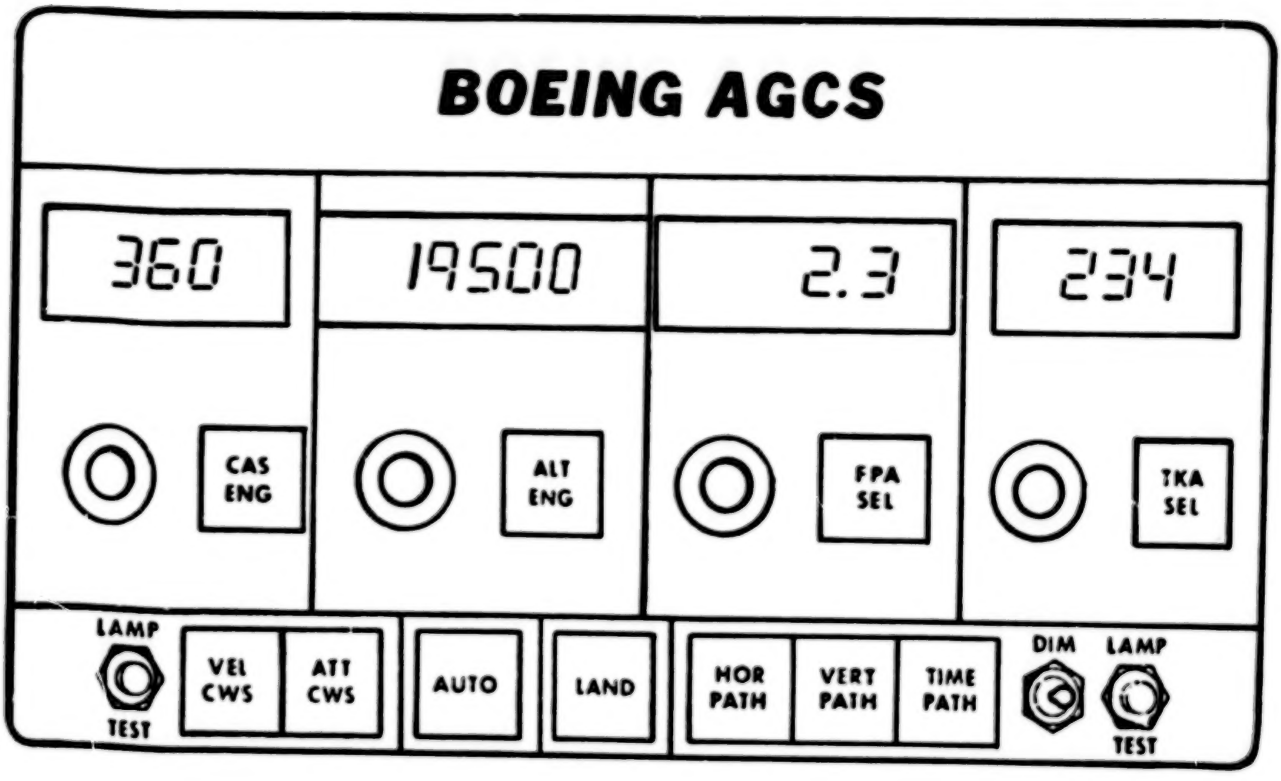


Figure 4. AGCS Panel

4. SCENARIOS

The scenarios used for the simulations are taken from the Harris and Mixon (1979) report. The only significant departure from the experimental conditions employed by Harris and Mixon is that no other air traffic is represented in the HOS simulation (i.e., only the "no traffic" condition is simulated). Both the straight-in and the curved approach paths used by Harris and Mixon are simulated. Five path segments are defined for each approach path; they are designated as Downwind, Base, and Turn, Approach, and Flare. Two autopilot control modes are used in the simulation, Velocity Control Wheel Steering (VCWS) and the Three-Dimensional Autopilot (3D-Auto). Only the VCWS control mode is used for the straight-in approach and for the final three segments of the curved approach. In one simulation the VCWS mode is used for the first two segments of the curved approach and in another the 3D-Auto mode is used for those two segments. Thus, three distinct simulations are generated by a single simulation program by varying the scenario conditions — a straight-in approach in VCWS mode, a curved approach in VCWS mode, and a curved approach that starts in 3D-Auto mode and ends in VCWS mode.

For each of the approach paths, six waypoints designate the path geometry. Associated with each waypoint are a desired altitude and airspeed. Table 1 presents the location and desired performance parameters for each waypoint on each approach path. The waypoint locations and approach path patterns are graphically illustrated in Figure 5. Note that the same waypoint names refer to different locations in the cases of the first four waypoints on the two paths. In addition to the waypoints, navigational information is obtained from ILS and MLS beacons and middle and outer marker beacons. The outer and middle markers are respectively 34,269 and 3,580 feet from the runway threshold along the localizer center path. The prescribed glideslope is 3°. The outer marker beacon is encountered only in the straight-in approach.

TABLE 1. MAP COORDINATES AND DESIRED ALTITUDES AND AIRSPEEDS FOR WAYPOINTS FOR STRAIGHT-IN AND CURVED APPROACH ROUTES. RUNWAY THRESHOLD IS AT (0,0) AND EXTENDS ALONG +X AXIS.

WAYPOINT	AIRSPEED (knots)	STRAIGHT-IN APPROACH			CURVED APPROACH		
		ALTITUDE, FT.	X, FT.	Y, FT.	ALTITUDE, FT.	X, FT.	Y, FT.
MERCI	210	1510	-65631	0	4902	-170	-45787
QUARY	185	1510	-55084	0	3500	-26662	-42064
RAPID	160	1510	-44536	0	2402	-33150	-26004
NORMA	140	1002	-17938	0	1002	-16774	-5004
DUBIL	130	384	-6433	0	384	-6433	0
GPIUL	130	0	860	0	0	860	0

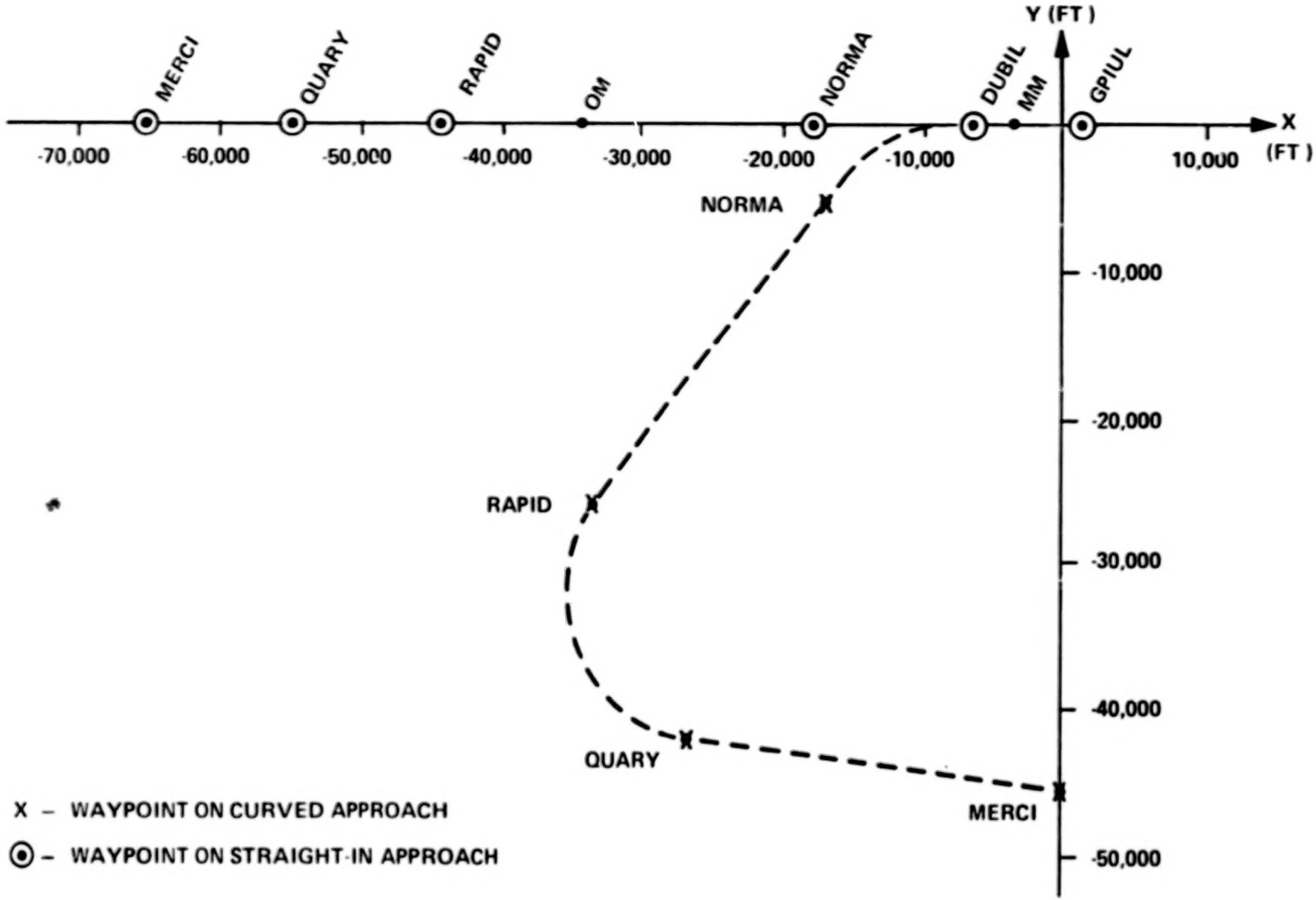


Figure 5. Straight-In and Curved Approach Patterns

The five flight segments are defined primarily, but not completely in terms of the waypoints. The Downwind segment extends from MERCI to QUARY. The Base segment extends from QUARY through RAPID to NORMA. The segment from NORMA to DUBIL is Turn. The Approach segment starts at DUBIL and terminates at the runway threshold (not a waypoint). Finally, the Flare segment extends from the runway threshold to GPIUL (the point of touchdown).

In both control modes, the pilot manages airspeed through the autothrottle subsystem of the Advanced Guidance and Control System (AGCS). In the VCWS mode, the pilot uses the Brolly handles to manipulate flight path angle and track angle with the autopilot maintaining both of these flight parameters when the pilot is not applying pressure on the handles. In the 3D-Auto mode, the autopilot assumes complete control over flight-path angle and bank angle in order to navigate between waypoints entered in the flight computer. The instruments of primary interest to the pilot are the EADI and EHSI. The pilot will continually cross-check these instruments against other instruments displaying aircraft performance information.

The specific control and monitoring tasks of the pilot vary across the flight segments and the control modes. The remainder of this section describes these tasks.

4.1 STRAIGHT-IN APPROACH IN VCWS MODE

4.1.1 MERCI to QUARY

The scenario begins with the localizer intercepted. The aircraft is at an altitude of 1510 feet and an airspeed of 210 kts. The flaps are set at 1. The pilot is holding a flight path angle of 0° to maintain level flight. This angle is held through waypoint RAPID. Immediately after waypoint MERCI, the pilot calls for a flap setting of 5 (to be implemented by the copilot) and selects an airspeed of 185 kts., which is entered on the Calibrated

Airspeed Select (CAS) panel, which is part of the AGCS Mode Control Panel. On the EADI, the pilot will monitor the flight path wedges (which should be at 0^0 on the pitch scale), the track angle scale (the track angle pointer should be aligned with the 0^0 point on the track angle scale through all segments), and the localizer scale (the pointer to be kept within 1/2 dot to the right or left of scale center). As each waypoint is neared, the EHSI and the barometric altimeter are closely monitored. The barometric altimeter becomes more important as each waypoint is neared in order to achieve the desired altitude at the waypoint.

4.1.2 QUARY to RAPID

Flying at 185 kts., the altitude of 1510 feet is maintained. Immediately after passing QUARY, the pilot calls for the flap setting of 15 and selects an airspeed of 160 kts.

4.1.3 RAPID to NORMA

The pilot selects an airspeed of 140 kts., calls for a flap setting of 25, and calls for lowering of the landing gear. He also monitors the glideslope indicator. When the glideslope indicator is approximately centered, he slowly decreases his flight path angle to -3^0, using the Brolly handles. When he is centered on the glideslope, the flight path angle will be -3^0. At this point, he removes his hands from the Brolly handles and the autopilot maintains the flight path angle. Shortly after passing RAPID the pilot begins monitoring for passage over the outer marker beacon which is indicated by an aural signal and flashing of the outer marker indicator light.

During this phase, the pilot arms the speed brake and calls for "landing checklist to flaps." Continued attention is given to the localizer scale, glideslope scale (to be kept within 1/2 dot up and down from center scale), EHSI, barometric altimeter (which must be 1000 feet at waypoint NORMA), the Instantaneous Vertical Speed Indicator (IVSI), which indicates the rate of descent (which should be 690 feet per minute), and airspeed (which should be 140 kts.).

4.1.4 NORMA to DUBIL

Flying at 140 kts., the aircraft passes waypoint NORMA. This is indicated on the EHSI when the aircraft symbol obscures the waypoint symbol. Immediately after this passage, the pilot calls for a flap setting of 30 and selects an airspeed of 130 kts. The aircraft is to be stabilized in its slot by a 400-foot altitude. The same instruments are monitored (for the same reasons) as between RAPID and NORMA, but with a target altitude of 384 feet at waypoint DUBIL.

4.1.5 DUBIL to GPIUL

Flying at a speed of 130 kts., descent is continued while the pilot listens for an aural signal indicating passage over the middle marker. This should occur at decision height (188 feet). As with the outer marker, the pilot verifies the aural signal by checking the middle marker beacon light which should be flashing.

There is an increased usage of the EADI during this flight segment. In addition to previously mentioned items on the EADI, as touchdown nears the pilot monitors the perspective runway and 1000-foot marker. The 1000-foot marker on the runway should be vertically aligned with the flight-path angle wedges. The error tolerances on the localizer and glideslope scales decrease to 1/4 dot for each display.

Maintaining an airspeed of 130 kts., the pilot calls for completion of the landing checklist and the flap setting of 40. The pilot executes the flare maneuver at an altitude of 50 feet (according to the radar altimeter display on the EADI) by pulling back on the Brolly handles. He continues descent to touchdown on the 1000-foot mark on the runway.

4.2 Curved Approach in VCWS Mode

4.2.1 MERCI to QUARY

The scenario begins with the aircraft flying a straight path with a heading of 278° and a flight path angle of -3°. The airspeed is 210 kts. and the flaps are set at 1. The pilot selects an airspeed of 185 kts. and, when the speed of 190 kts. is reached, calls for a flap setting of 5. The pilot will monitor heading information on the EHSI to keep his track on the next waypoint. He will also monitor the flight-path wedges (Gamma Wedges) to keep them at -3° on the pitch scale. Finally, the Instantaneous Vertical Speed Indicator (IVSI) and barometric altimeter will be monitored. The IVSI informs the pilot of the rate of descent (which should be 980 feet/minute at 185 kts.). The barometic altimeter will be monitored as each waypoint is neared to ensure that the desired altitude is achieved.

4.2.2 QUARY to RAPID

Flying at 185 kts. with flaps set at 5, the aircraft is at an altitude of 3500 feet at QUARY. The heading is 278°. Immediately after passing waypoint QUARY, the pilot selects an airspeed of 160 kts. and initiates a turn to waypoint RAPID.

The pilot will use the curved trend vector on the EHSI to execute turns from one waypoint to the next. As the aircraft passes through the waypoint where the turn is to start, the pilot will roll the aircraft with the Brolly handle until the curved trend vector intersects the next waypoint at which the turn is to end and then initiate a deceleration through the CAS autothrottle. During the course of deceleration (which will be at a rate of about 1 kt./sec.) the pilot will have to continually adjust the aircraft turn rate with the Brolly handles. As the aircraft speed decreases, a fixed bank angle will result in a tighter turn, so the pilot must gradually reduce the bank angle while the speed decreases in order to maintain a constant turn radius. When the deceleration is complete, the pilot can release pressure

on the Brolly handles and the autopilot will hold the bank angle (and, hence, the turn radius) through the remainder of the turn. Just as the aircraft reaches the terminal waypoint for a turn, the pilot will abruptly roll the aircraft back to level flight. It will be assumed that there will be negligible lags between the pilot control actions to change aircraft attitude and flight-path angle and the aircraft responses to those control actions.

The desired airspeed at waypoint RAPID is 160 kts., and at the assumed deceleration rate of 1 kt./sec. that speed is attained approximately 25 seconds after it is selected, or about halfway between QUARY and RAPID. When the speed of 170 kts. is reached, the pilot calls for a flap setting of 15. Principal instruments monitored during this portion of the approach path are the curved vector on the EHSI, the roll indicator, and the CAS display. The desired altitude at RAPID is 2,402 feet.

4.2.3 RAPID to NORMA

Flying at a speed of 160 kts., the flaps are set at 15. The pilot changes his EHSI scale to 1 nm/in. The pilot selects an airspeed of 140 kts. When the aircraft reaches 150 kts., the pilot calls for a flap selection of 25; he also calls for "landing checklist to flaps" and lowering of the landing gear. He then arms the speed brake. The pilot continues descent on a flight-path angle of -3° which corresponds to a vertical speed of 742 feet/min. at 140 kts.

4.2.4 NORMA to DUBIL

Flying at 140 kts. the aircraft passes waypoint NORMA and the pilot calls for a flap setting of 30 and selects an airspeed of 130 kts. Descent continues on a -3° flight path angle which translates to a vertical descent rate of 689 feet/min. at 130 kts. At NORMA the pilot initiates a turn that terminates at DUBIL and changes the aircraft heading by 52° from 38° to 90°. The turn is executed by using the curved trend vector in the same manner as described above for the turn from QUARY to RAPID.

4.2.5 DUBIL to GPIUL

The flight path from DUBIL to GPIUL is the same for the curved approach as for the straight-in approach. Thus, the pilot procedures for this portion of the curved path are as described in paragraph 4.1.5 above.

4.3 CURVED APPROACH IN 3D-AUTO MODE

The procedures for flying the curved approach in 3D-Auto mode are essentially the same as those for flying the path in VCWS mode. The key differences are that in 3D-Auto mode, the autopilot rather than the pilot initiates and terminates each turn. Thus, in 3D-Auto mode, the pilot monitors the performance of the autopilot in executing the turns starting at waypoints QUARY and NORMA. If any errors are observed in autopilot control, after cross-checking the relevant displays, the pilot switches to the VCWS control mode. Upon completing the turn at NORMA in 3D-Auto mode, the pilot pushes the VEL-CWS button on the AGCS Mode Select Panel which changes the control mode from 3D-Auto to VCWS. (Actually, the preferred procedure for transferring from 3D-Auto to VCWS mode is for the pilot to make any control input with the Brolly handles. However, the non-preferred procedure of pressing the VEL-CWS button is used here because it would be difficult to simulate the more complex hardware dynamics associated with the preferred procedure and because the procedure will be performed only once in a landing scenario and thus have negligible impact on simulation results.) The pilot then completes the approach in VCWS mode as described above.

5. SIMULATION STRATEGY

In developing a simulation of a complex system there are many options with respect to level of detail, organization, and overall flexibility of process representation. Selections among these options are critical to the success of any simulation program. Choices of simulation features must be balanced against one another and weighed with respect to resource constraints and ultimate objectives. In the case of the present study, the principal immediate objective is the simulation of pilot and aircraft performance using a single crewstation configuration under two alternative control modes and under two flight path scenarios.

Since a central concern of the study is the comparison of eye scanning data across three different control mode/flight path situations, it is important that the three simulations properly represent the commonalities and differences across these situations. Two techniques have been used to achieve this type of comparability. First, the simulations have been developed with general operator and hardware procedures that can be applied to any approach path geometry by appropriate choice of input parameters. Thus, the same simulation program is used for both the curved and straight-in approach patterns. Second, simulation procedures and functions for the 3D-Auto control mode have been developed through minimal adaptation from the analogous VCWS mode procedures and functions. By maintaining maximal similarities between the two simulation programs, it is possible to minimize the effects on simulation results (regarding comparisons between cases) of particular choices for input parameter values.

The consideration of appropriate levels of detail for the HOS simulations has focused principally on the competing issues of the complexity and cost of a highly detailed simulation of aircraft and instrument dynamics and the impact on operator performance of the various components of system dynamics. For the case of the VCWS control mode, in particular, it is clear that some degree of operator control over aircraft motion must be modeled since flight-path errors generated by the operator will be a significant determinant of the frequency and duration of compensatory control actions. Rather than undertake an elaborate model of aerodynamic behavior, however, it was determined that a minimal model of aircraft kinematics could provide an adequate description of aircraft response to pilot control manipulations. Accordingly, it is assumed that airspeed and flight-path angle will change at constant rates toward the values commanded by the pilot (through the CAS-ENG display on the AGCS panel and the command gamma wedges on the EADI display) whenever they are not at the commanded values and that they will be stabilized by the autopilot at those values when they are attained. For aircraft turns it is assumed that the turn radius depends only on airspeed and bank angle according to the formula,

$$R = \frac{S^2}{g \tan B}$$

where R is turn radius, S is airspeed, B is bank angle, and g is the gravitational acceleration constant. The model for operation of the Brolly handles describes rate of change of the aircraft bank angle varying in proportion to the rotational force on the handles. Although in the actual TCV there is a similar correspondence between the longitudinal force on the Brolly handles and the rate of movement of the command gamma wedges, it was found that modeling of pilot control with this correspondence could not be achieved without resorting to excessively complex adjustment procedures. Consequently, it has been assumed for the sake of expediency that there is a direct positional correspondence between the longitudinal component of the Brolly handles and the value of the command gamma wedges.

For the 3D-Auto control mode, it is unnecessary for the HOS simulation to describe the intricate dynamics of the autopilot system. Assuming that the autopilot functions properly, the pilot will not perform any control adjustments with the Brolly handles while the 3D-Auto mode is engaged. Accordingly, it is assumed in this mode that the aircraft flies a predetermined, typical flight path which is provided as input to the HOS simulation. It is important in this case, that realistic path errors be generated because the relative magnitudes of the various error components are significant determinants of the relative frequencies with which different monitoring operations are performed.

The complete HOPROC and FORTRAN code for the simulations are listed in Appendix A. Although brief descriptions of the procedures and functions are included in the appendix, reference to the HOS Study Guide (Strieb, Glenn, and Wherry, 1978) is encouraged for a complete discussion of HOPROC language features and other HOS characteristics. Input parameters to the HOS simulations are described and listed in Appendix B.

6. SIMULATION RESULTS

Three aspects of simulation results will be described in this section. First, the issue of how effectively the simulated pilot performed in controlling the aircraft will be addressed. Second, simulation data on eye fixations and movements will be compared to the experimental data reported by Harris and Mixon. Finally, samples of a variety of HOS output options will be presented in order to illustrate system capabilities.

6.1 EFFECTIVENESS OF AIRCRAFT CONTROL

The achievement of adequate aircraft control by the pilot was a major objective in the development of simulation procedures. Although it was clear at the outset of this work that discovery of actual control procedures used by aircraft pilots would be a major undertaking beyond the scope of this initial effort, it was expected that plausible procedures could be constructed which would enable complete execution of the desired scenarios. In fact, the effort that was required to develop the current control procedures was considerably greater than originally anticipated. Also, while the current operator procedures seem to produce adequately realistic control performance, a few significant shortcomings remain to be remedied.

Operator control procedures are an issue only in the VCWS control mode. The major control problems are associated with the maneuvers to compensate for localizer, glideslope, and heading errors and to execute turns from waypoint to waypoint. Since the "turn-to-waypoint" procedure is treated as a procedure to correct the discrepancy between the curved trend vector on the EHSI and the location of the next waypoint, all of the major control procedures are essentially error-correcting procedures.

In every case, the procedures involve compensatory tracking — making control inputs to keep an error signal within acceptable bounds. A number of alternative methods of modeling the operator's behavior must be considered in each procedure:

1. Should the operator initiate a gradual movement of the controlled element and actively terminate the movement when the desired value is obtained, or should "ballistic" adjustments be used with a check being made at the end of each adjustment to see if the desired value has been reached?

2. When procedures interact, as with the localizer and heading adjustment procedures, should they be performed in sequence or in some combined manner?

3. What rates of adjustment should be used?

4. What error limits should be used to trigger adjustments and what limits should suffice for the termination of those adjustments?

5. How should selection from all of these options vary with situational characteristics?

The last of the above questions has posed the greatest difficulty in the development of effective control procedures. Adjustment procedures which work well in one situation do not necessarily work well in other situations. This problem is particularly evident in the case of the procedures to adjust localizer and glideslope errors. When the aircraft is fairly far from the runway (and hence from the glideslope and localizer beacons) it takes much longer for an aircraft maneuver to compensate for a given angular error than when the aircraft is near the runaway. Thus, when the aircraft is far from the runway, an appropriate control strategy is for the pilot to change heading or flight-path angle (for localizer or glideslope, respectively) in order to reduce the error, to monitor the error until it is near zero, and then to resume the desired heading or flight-path angle. In fact, this description applies to the adjustment procedures used in the HOS-TCV simulations under all conditions. However, as the aircraft nears the runway, this type of adjustment procedure runs into difficulty because error values respond very quickly to aircraft

manuevers, so there is a strong tendency for the pilot to overshoot the desired value. Consequently, in the present simulations, control effectively breaks down near the decision altitude; the pilot spends all of his time trying to control glideslope and localizer errors which oscillate from one extreme to the other and the pilot neglects other control functions that are critical to a successful landing. The solution to this problem is to make the pilot transition from the continuous monitoring procedure described above to a ballistic adjustment procedure (i.e., one in which the control maneuver is initiated and terminated without intermediate error monitoring) as the runway is approached. Unfortunately, the scope of the present effort did not permit the development of this type of hybrid control procedure.

Other than the exceptions just noted, control operations functioned adequately. Turns from waypoint to waypoint appeared realistic, bringing the aircraft acceptably close to each waypoint. The initial capture of the glideslope in the straight-in approach was successful. Localizer and heading adjustments that occurred prior to arrival at the middle marker were reasonably accurate.

6.2 COMPARISON BETWEEN SIMULATION AND EXPERIMENTAL DATA

Since the current simulations represent essentially a very rough first cut at the problem of describing pilot controlling procedures with the HOS model, only limited, general comparisons are warranted between the simulation data and the oculometer data collected by Harris and Mixon. One useful comparison is to examine the relative amounts of time spent by the pilot in viewing his two principal instrument panels, the EADI and the EHSI, on different path segment in different scenarios. Table 2 displays the relative amounts of time that the real and simulated pilots spent viewing these panels under the different conditions. (Percentages of time spent viewing other display panels are presented in Table 3. A description of the instrument groupings for each panel designation can be found in the discussion of the Link Analysis in Section 6.3.) Three general trends can be discerned in the experimental data, although data relevant to the statistical significance of these trends was not reported by Harris and Mixon. Those trends are:

Table 2. Percentage of Total Time Spent Viewing EADI and EHSI Instrument Panels

	EADI-Experiment			EADI-Simulation		
Segment	Straight VCWS	Curved VCWS	Curved 3D-Auto	Straight VCWS	Curved VCWS	Curved 3D-Auto
DOWNWIND	64	62	44	69	68	61
BASE	79	47	38	67	62	61
TURN	87	63	59*	63	71	64*
APPROACH	94	96	96*	92	91	84*
FLARE	97	98	95*	86	90	54*

	EHSI-Experiment			EHSI-Simulation		
Segment	Straight VCWS	Curved VCWS	Curved 3D-Auto	Straight VCWS	Curved VCWS	Curved 3D-Auto
DOWNWIND	8	23	27	8	13	12
BASE	3	42	39	8	11	12
TURN	1	31	34*	10	5	9*
APPROACH	0	0	0*	2	4	3*
FLARE	0	0	0*	0	10	0*

*-VCWS control mode

Table 3. Percentage of Total Time Spent Viewing Instrument Panels Other Than the EADI and EHSI in the Simulation

	Center Panel			Pilot's Panel		
Segment	Straight VCWS	Curved VCWS	Curved 3D-Auto	Straight VCWS	Curved VCWS	Curved 3D-Auto
DOWNWIND	5	10	10	7	4	11
BASE	8	9	10	7	10	10
TURN	8	5	12*	8	6	8*
APPROACH	2	0	5*	0	1	4*
FLARE	4	0	5*	0	0	0*

	Center Controls			Pilot's Controls		
Segment	Straight VCWS	Curved VCWS	Curved 3D-Auto	Straight VCWS	Curved VCWS	Curved 3D-Auto
DOWNWIND	7	2	2	5	2	4
BASE	4	2	2	5	4	4
TURN	6	4	4*	4	6	3*
APPROACH	0	0	1*	0	0	0*
FLARE	0	0	0*	0	0	0*

*-VCWS control mode

1. As the runway is approached for each control mode and approach path, the dwell percentage on the EADI increases to nearly 100% and the dwell percentage on the EHSI decreases to 0%.

2. For the first three path segments (i.e. the segments for which the curved and straight-in approaches differ), the dwell percentage for the EADI on the straight approach exceeds that for the EADI on the curved approach and the dwell percentage for the EHSI on the straight approach is less than that for the EHSI on the curved approach.

3. For the first two path segments on the curved approach, the dwell percentage for the EADI under the VCWS mode exceeds that for the EADI under the 3D-Auto mode and the dwell percentages for the EHSI under both control modes are about equal.

Only the first of these trends appears to be replicated in the simulation data. This trend represents an increased reliance on EADI information as the touchdown point is approached. One important cause for this trend is the increasing difficulty of keeping glideslope and localizer errors within limits as the runway is neared.

The second of the above trends indicates an increase in use of the EHSI and a corresponding decrease in use of the EADI during turn maneuvers prior to the final approach. It is rather surprising that this trend is not replicated in the simulation data since the "turn-to-waypoint" procedure used in the HOS simulations focuses principally on adjustment of the curved trend vector on the EHSI. However, although that procedure uses the curved trend vector to adjust the aircraft turn, the procedure calls for the pilot to translate the perceived error in the turn curvature into a desired change to aircraft bank angle. Since it takes the pilot much longer to adjust the bank angle (which requires continuous monitoring of the roll indicator on the EADI) than to perceive the turn error on the EHSI, the observed dominance of the EADI in the simulation data can be explained. Thus, it seems that a more realistic turn-to-waypoint procedure would use the curved trend vector to monitor turn progress without translating to bank angle changes and, perhaps, just check bank angle occasionally to keep it within allowable limits.

The third of the trends described above indicates greater use of the EADI under VCWS than under 3D-Auto control while use of the simulation EHSI does not appear to vary across the control modes. This trend would suggest that most control manipulations draw more heavily on EADI information than on EHSI information. Since the effect is rather small in the experimental data and since the interpretation is questionable, no clear conclusion can be drawn from the failure of the simulation data to display the same trend. However, similar trends have been reported in previous studies using electromechanical displays (e.g., Spady, 1978).

In general, the correspondence between the experimental and simulation data is encouraging, the absolute levels for the dwell percentages displayed in Table 2 agree quite well between the experiment and the simulation. One interesting trend in the experimental data is replicated by the simulation and it is clear that the other observed trends could also be replicated with some minor modifications to simulation procedures. Of course, other more detailed measures of correspondence could be used. However, systematic examination of details such as dwell times and link frequencies is appropriately postponed until currently identified procedure refinements are made to produce acceptable aircraft control and a reasonable correspondence between experiment and simulation.

6.3 SAMPLE HOS OUTPUTS

Complete simulation outputs would be much too voluminous to be included in this report, so samples of just a few output options will be presented to illustrate the variety of outputs that can be generated.

A portion of the standard HOS report of simulation events is presented in Figure 6. In that report simulation time in seconds is indicated in the left column followed by a brief description of each simulation event. When the event consists of initiation of work on an operator procedure, then the description is just the name of the procedure shifted five characters to the left of the other event descriptions. The first line of the report in the figure indicates the initiation of the procedure FLY-TO-WAYPOINT.

OPERATOR			BODY RH	BODY LH	BODY RF	BODY LF	BODY E	HARDWARE	
.67	FLY TO WAYPOINT								
.67	COMPUTE COURSE CHANGE								
.70	ABSORB WAYPOINT 1 POSITION						X		
.94	WAYPOINT 1 POSITION	= (-55084.3, 0.0)						(-55084.3,	0.0)
.96	ABSORB AIRCRAFT POSITION						X		
1.20	AIRCRAFT POSITION	= (-65289.3, -11.0)						(-65212.5,	-14.6)
1.24	ABSORB TRACK BOX						X		
1.27	TRACK BOX	= 92.0						92.0	
1.29	COURSE CHANGE	= 0.0							
1.29	IF 164								
1.30	IF 168								
1.31	ALTER 172								
1.35	ABSORB WAYPOINT 1 SPEED						X		
1.59	WAYPOINT 1 SPEED	= 185.0						185.0	
1.59	STEP CRIT								
1.59	ALTER 175								
1.59	COMPUTE FLY TO CRIT								
1.61	ABSORB AIRCRAFT POSITION						X		
1.65	AIRCRAFT POSITION	= (-65060.3, -19.0)						(-65049.8,	-20.3)
1.67	ABSORB WAYPOINT 1 POSITION						X		
1.71	WAYPOINT 1 POSITION	= (-55084.3, 0.0)						(-55084.3,	0.0)
1.72	FLY TO CRIT	= 1.5							
1.72	IF 177								
1.72	COMPUTE DIST TO WAYPOINT								
1.74	ABSORB AIRCRAFT POSITION						X		
1.78	AIRCRAFT POSITION	= (-65014.3, -21.0)						-65003.8,	-21.9)
1.80	ABSORB WAYPOINT 1 POSITION						X		
1.84	WAYPOINT 1 POSITION	= (-55084.3, 0.0)						(-55084.3,	0.0)
1.94	DIST TO WAYPOINT	= 9930.0							
1.94	COMPUTE WAYPOINT CLOSE								
2.04	WAYPOINT CLOSE	= 2000.0							

Figure 6. Standard HOS Output

The beginning of the computation of a function or the reading of a device value is indicated by the word COMPUTE or the word ABSORB followed by the function or device name. When the evaluation process is completed, the estimated value of the function or device is indicated with that event description being shifted four characters to the right. When IF and ALTER statements are processed, the description consists just of the word IF or ALTER followed by an index number that refers to the location of the relevant HOPROC instruction in the assembled program code. On the right side of the HOS output in Figure 6 are columns indicating which body part is used for each absorption or manipulation (RH-right hand, LH-left hand, RF-right foot, LF-left foot, E-eyes) and a column labeled HARDWARE which displays actual values of devices that correspond to estimated values that result from absorption events.

The remaining HOS output options require that the file of simulation events be processed by the HODAC program. Figure 7 displays a segment of a Timeline Analysis which indicates which procedure or body part action consumed the most time during each time interval. Time interval size is selected by the user (a one-second interval is used in the report in Figure 7). A line of dots indicates a continuation of the preceding procedure or action, while a blank entry in a body part column means that the body part is inactive during the indicated interval. Figure 8 presents part of a Channel Loading Report which, like the Timeline Analysis, has a user-selectable time interval. For each time interval in the Channel Loading Report, the percentage of time active is indicated for each body part and for mental channel which performs function computations. Percentages are indicated both numerically and graphically as a line of asterisks, each asterisk representing ten percent.

A portion of a Device Analysis by Body Part is displayed in Figure 9. Under the column titled DEVICE on the left of the report are the names of devices followed by three categories of events involving

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HODAC BODY PART TIMELINE ANALYSIS (1.0 SECOND SNAPSHOTS)

TIME	EXECUTING	EYES ARE	RIGHT HAND IS	LEFT HAND IS	RIGHT FOOT IS	LEFT FOOT IS
0.0	MISSION	ABSORBING FROM WAYPOINT 1 POSITION		MANIPULATING START SIMULATION		
1.0	FLY TO WAYPOINT	ABSORBING FROM WAYPOINT 1 SPEED				
2.0	&COMMAND GAMMA	ABSORBING FROM COMMAND GAMMA		MANIPULATING BROLLY PITCH		
3.0	&STRAIGHT VECTOR	MOVING TO AIRCRAFT POSITION				
4.0	. . . . .	ABSORBING FROM ROLL INDICATOR		ABSORBING FROM BROLLY ROLL		
5.0	. . . . .	MOVING TO ROLL INDICATOR				
6.0	. . . . .	. . . . .				
7.0	. . . . .	MOVING TO TRACK BOX				
8.0	. . . . .	. . . . .				
9.0	. . . . .	MOVING TO ROLL INDICATOR				
10.0	&ROLL INDICATOR	ABSORBING FROM ROLL INDICATOR		MANIPULATING BROLLY ROLL		
11.0	. . . . .	MOVING TO AIRCRAFT POSITION		MANIPULATING BROLLY PITCH		
12.0	&CAS ENG DISPLAY	ABSORBING FROM CAS ENG DISPLAY	MOVING TO CAS ENG KNOB	. . . . .		
13.0	. . . . .	MOVING TO AIRCRAFT POSITION	MANIPULATING CAS ENG KNOB			
14.0	&REVIEW MONITORS	ABSORBING FROM WAYPOINT 5 POSITION	. . . . .			
15.0	. . . . .	ABSORBING FROM WAYPOINT 1 NAME	MOVING TO RIGHT BROLLY HANDLE			
16.0	&STRAIGHT VECTOR	MOVING TO AIRCRAFT POSITION				

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Figure 7. Timeline Analysis

HODAC CHANNEL LOADING REPORT (1.0 SECOND SNAPSHOTS)

TIME	EYES		MENTAL		RIGHT HAND		LEFT HAND		RIGHT FOOT		LEFT FOOT
1.00	100.0	**********	69.7	*******	0.0		1.0		0.0		0.0
2.00	80.2	********	68.1	*******	0.0		0.0		0.0		0.0
3.00	74.8	*******	44.2	****	0.0		35.0	***	0.0		0.0
4.00	83.0	********	33.5	***	0.0		0.0		0.0		0.0
5.00	73.0	*******	68.8	*******	0.0		8.0	*	0.0		0.0
6.00	71.0	*******	37.0	****	0.0		0.0		0.0		0.0
7.00	64.0	******	41.1	****	0.0		0.0		0.0		0.0
8.00	68.2	*******	37.0	****	0.0		0.0		0.0		0.0
9.00	66.8	*******	38.1	****	0.0		0.0		0.0		0.0
10.00	65.5	*******	36.9	****	0.0		0.0		0.0		0.0
11.00	57.5	******	54.2	*****	0.0		15.0	*	0.0		0.0
12.00	54.0	*****	60.4	******	0.0		35.7	****	0.0		0.0
13.00	64.6	******	50.5	*****	6.4	*	5.1	*	0.0		0.0
14.00	26.6	***	18.6	**	89.2	*********	0.0		0.0		0.0
15.00	48.7	*****	72.4	*******	50.0	*****	0.0		0.0		0.0
16.00	66.9	*******	46.8	*****	27.5	***	0.0		0.0		0.0
17.00	79.2	********	39.2	****	0.0		0.0		0.0		0.0
18.00	61.8	******	55.4	******	0.0		0.0		0.0		0.0
19.00	99.0	**********	54.5	*****	0.0		0.0		0.0		0.0
20.00	85.0	********	28.3	***	0.0		0.0		0.0		0.0
21.00	66.0	*******	63.0	******	0.0		0.0		0.0		0.0
22.00	87.0	*********	52.4	*****	0.0		0.0		0.0		0.0
23.00	80.0	********	57.7	******	0.0		0.0		0.0		0.0
24.00	89.0	*********	47.3	*****	0.0		0.0		0.0		0.0
25.00	83.0	********	41.0	****	0.0		0.0		0.0		0.0
26.00	71.4	*******	58.6	******	0.0		0.0		0.0		0.0
27.00	96.6	**********	64.7	******	0.0		0.0		0.0		0.0
28.00	76.0	********	38.0	****	0.0		0.0		0.0		0.0
29.00	63.0	******	55.3	******	0.0		0.0		0.0		0.0
30.00	34.5	***	64.0	******	0.0		0.0		0.0		0.0
31.00	66.5	*******	31.4	***	0.0		0.0		0.0		0.0

Figure 8. Channel Loading Report

HODAC DEVICE ANALYSIS BY BODY PART

DEVICE	EYES				RIGHT HAND				LEFT HAND				RIGHT FOOT				LEFT FOOT			
	SUM	N	AVG	SD	SUM	N	AVG	SD	SUM	N	AVG	SD	SUM	N	AVG	SD	SUM	N	AVG	SD
BARO ALTIMETER THOU																				
MOVING/GRASPING	1.50/	19=	.08;	.023																
ABSORBING-COMPUTING	3.08/	19=	.16;	.030																
MANIPULATION-RECALL																				
BARO ALTIMETER HUND																				
MOVING/GRASPING																				
ABSORBING-COMPUTING	3.12/	19=	.16;	.032																
MANIPULATION-RECALL																				
VSI																				
MOVING/GRASPING	1.60/	19=	.08;	.024																
ABSORBING-COMPUTING	3.08/	19=	.16;	.033																
MANIPULATION-RECALL																				
MACH INDICATOR																				
MOVING/GRASPING																				
ABSORBING-COMPUTING	2.60/	15=	.17;	.028																
MANIPULATION-RECALL																				
AIRSPEED INDICATOR																				
MOVING/GRASPING	5.50/	53=	.10;	.051																
ABSORBING-COMPUTING	3.04/	53=	.06;	.037																
MANIPULATION-RECALL																				
SPEED BRAKE LEVER																				
MOVING/GRASPING					.40/	1=	.40;0.000													
ABSORBING-COMPUTING					.04/	1=	.04;0.000													
MANIPULATION-RECALL					1.50/	1=	1.50;0.000													
CRUISE LAND TST KNOB																				
MOVING/GRASPING	4.74/	39=	.12;	.004																
ABSORBING-COMPUTING	1.08/	39=	.03;	.011																
MANIPULATION-RECALL																				
MAP SCALES																				
MOVING/GRASPING	.34/	3=	.11;	.012	.86/	2=	.43;0.000													
ABSORBING-COMPUTING	.64/	3=	.21;	.019																
MANIPULATION-RECALL					.20/	2=	.10;0.000													

Figure 9. Device Analysis By Body Part

the device -- MOVING/GRASPING, ABSORBING-COMPUTING, and MANIPULATION-RECALL. MOVING/GRASPING refers to time spent moving a body part to or grasping a device. ABSORBING-COMPUTING refers to time spent absorbing a device value or computing the value of a function. MANIPULATION-RECALL refers to time spent manipulating a control or recalling a display, symbol, or function value. Under the columns for each body part, statistics are indicated for the total time spent in each event category for the device (SUM), the total number of events in that category that occurred (N), the average time consumed by each event (AVG), and the standard deviation of the event times (SD).

Figure 10 presents a segment of a Label Analysis. This analysis provides data on the times when each procedure was first and last activated, executed, and removed from the active list. Additionally, for procedures that contain internal statement labels, the report indicates a variety of time statistics pertaining to encounters of the labeled statements. A complete explanation of those statistics is offered in Strieb, Glenn, and Wherry (1978).

Figures 11 and 12 present samples of the two parts of the HODAC Link Analysis. It was these analyses that were used to generate the dwell time statistics presented in Table 2. For this analysis, devices are combined into groups such as Center Panel and EADI in order to make the link statistics manageable. With reference to the listing of HOPROC variable names for the Display, Control, and Symbol Sections as listed on pages 63 through 66 of Appendix A, the following assignments indicate how HOPROC variables were grouped for the Link Analysis:

CENTER-PANEL = CAS-ENG-DISPLAY through TKA-SEL-LIGHT

EADI = EADI through TRACK-POINTER

EHSI = EHSI through WIND-VELOCITY and AIRCRAFT-SYMBOL through WAYPOINT-5-POSITION

PILOTS-PANEL = BARO-ALTIMETER-THOU through MIDDLE-BEACON-LIGHT

CENTER-CONTROLS = [illegible]VS-SWITCH through VERT-PATH-SWITCH and WPT-ALT through TRACK-UP-SWITCH and SPEED-BRAKE-LEVER through AUTO-MANUAL-SWITCH

HOBAC LABEL ANALYSIS

-$AIRSPEED CHECK	FIRST ACTIVATED	.67	LAST ACTIVATED	
	FIRST EXECUTED	26.03	LAST EXECUTED	306.76
	NEVER REMOVED			
-NOTIFY ATC	FIRST ACTIVATED	154.27	LAST ACTIVATED	334.26
	FIRST EXECUTED	154.27	LAST EXECUTED	334.26
	FIRST REMOVED	154.27	LAST REMOVED	334.26
-$ALTITUDE CHECK	FIRST ACTIVATED	.67	LAST ACTIVATED	
	FIRST EXECUTED	21.78	LAST EXECUTED	294.03
	NEVER REMOVED			
-APPROACH WAYPOINT	FIRST ACTIVATED	83.63	LAST ACTIVATED	332.24
	FIRST EXECUTED	83.63	LAST EXECUTED	334.26
	FIRST REMOVED	86.50	LAST REMOVED	334.94
-TURN TO WAYPOINT	FIRST ACTIVATED	87.12	LAST ACTIVATED	271.08
	FIRST EXECUTED	90.80	LAST EXECUTED	320.21
	FIRST REMOVED	158.65	LAST REMOVED	321.12

LABEL	TOTAL TIME TO:	ACTIVE TIME TO:	NUMBER OF ENCOUNTERS:	ENCOUNTERS:
AUTO	0.00/ 2= 0.00; 0.00	0.00/ 2= 0.00; 0.00	2/ 2= 1.00	2/ 2=100.00
MANUAL	.38/ 2= .19; 0.00	.38/ 2= .19; 0.00	2/ 2= 1.00	2/ 2=100.00
ENDAUT	0.00/ 0= 0.00; 0.00	0.00/ 0= 0.00; 0.00	0/ 2= 0.00	0/ 2= 0.00
CYCLE	7.73/ 2= 3.86; .03	7.73/ 2= 3.86; .03	19/ 2= 9.50	2/ 2=100.00
STOP	60.40/ 2= 30.20; 3.38	60.40/ 2= 30.20; 3.38	13/ 2= 6.50	2/ 2=100.00

-ROLL OUT	FIRST ACTIVATED	10.02	LAST ACTIVATED	359.80
	FIRST EXECUTED	10.02	LAST EXECUTED	361.67
	FIRST REMOVED	11.57	LAST REMOVED	361.68
-$BROLLY ROLL	FIRST ACTIVATED	91.51	LAST ACTIVATED	275.73
	FIRST EXECUTED	91.51	LAST EXECUTED	278.18
	FIRST REMOVED	94.69	LAST REMOVED	278.86

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Figure 10. Label Analysis

HODAC LINK ANALYSIS
LINK MOVEMENTS

TO EADI

FROM	EYES	RIGHT HAND	LEFT HAND	RIGHT FOOT	LEFT FOOT
CENTER PANEL					
MOVEMENT TIME	16.02/ 99= .16; .016				
TOTAL IDLE/DWELL	8.08/ 99= .08; .091				
ACTIVE TIME	5.52/ 99= .06; .069				
IDLE TIME	2.56/ 99= .03; .034				
EADI					
MOVEMENT TIME	27.10/857= .03; .019				
TOTAL IDLE/DWELL	90.46/857= .11; .117				
ACTIVE TIME	42.22/857= .05; .034				
IDLE TIME	48.24/857= .06; .107				
EHSI					
MOVEMENT TIME	6.69/157= .04; .012				
TOTAL IDLE/DWELL	12.22/157= .08; .052				
ACTIVE TIME	7.01/157= .04; .031				
IDLE TIME	5.21/157= .03; .050				
PILOTS PANEL					
MOVEMENT TIME	3.81/ 55= .07; .011				
TOTAL IDLE/DWELL	13.86/ 55= .25; .124				
ACTIVE TIME	9.52/ 55= .17; .118				
IDLE TIME	4.34/ 55= .08; .061				
CENTER CONTROLS					
MOVEMENT TIME	4.60/ 38= .12; .018				
TOTAL IDLE/DWELL	4.23/ 38= .11; .183				
ACTIVE TIME	1.02/ 38= .03; .012				
IDLE TIME	3.21/ 38= .08; .188				
PILOTS CONTROLS					
MOVEMENT TIME	.28/ 3= .09; .032				
TOTAL IDLE/DWELL	1.34/ 3= .45; .317				
ACTIVE TIME	.06/ 3= .02; .014				
IDLE TIME	1.28/ 3= .43; .303				

Figure 11. Link Movements Analysis

HOBAC LINK ANALYSIS
LINK FREQUENCIES

	EYES(1852)	R. HAND(39)	L. HAND(0)	R. FOOT(0)	L. FOOT(0)
CENTER PANEL					
ALL CENTER PANEL	9 / .486%				
TO EADI	129 / 6.965%				
FROM EADI	99 / 5.346%				
ALL EADI	228 / 12.311%				
TO EHSI	23 / 1.242%				
FROM EHSI	17 / .918%				
ALL EHSI	40 / 2.160%				
TO PILOTS PANEL	4 / .216%				
FROM PILOTS PANEL	17 / .918%				
ALL PILOTS PANEL	21 / 1.134%				
TO CENTER CONTROLS					
FROM CENTER CONTROLS	15 / .810%				
ALL CENTER CONTROLS	15 / .810%				
TO PILOTS CONTROLS	2 / .108%				
FROM PILOTS CONTROLS	10 / .540%				
ALL PILOTS CONTROLS	12 / .648%				
TO RELAXATION					
FROM RELAXATION					
ALL RELAXATION					

Figure 12. Link Frequencies Analysis

PILOTS-CONTROLS = BROLLY-PITCH through START-SIMULATION.

Figure 11 illustrates the Link Movements portion of the analysis which displays time statistics for link movements. As indicated at the top of the sample report, the displayed portion of the report pertains to movements to the EADI from the device groups listed in the left column. Four categories of activity are indicated under each group name in the left column — Movement Time, Total Idle/Dwell, Active Time, and Idle Time. Movement Time refers to the time spent in moving each body part from a device in the from-group to a device in the to-group. Total Idle/Dwell refers to the sum of the times in the Active Time and Idle Time categories. Active Time refers to the time that the body part spent actively manipulating or absorbing from the device in the from-group prior to moving to the to-group. Idle Time refers to the time that the body part spent in idle contact with the device in the from-group prior to moving to the to-group. Under the column for each body part, four statistics are indicated — total time spent in the event category, number of links, average event time, and standard deviation of event times. Statistics for movements between devices in a single panel are indicated under the cells for which that panel name serves as the title of both the from-group and the to-group. Figure 12 illustrates the Link Frequencies portion of the Link Analysis which indicates the proportion of total movements of each body part that were between devices in the indicated groups. The total number of movements made by each body part are indicated in parentheses next to the name of the body part at the top of the report.

For further discussion of the use and interpretation of these as well as several other report options, the interested reader is referred to the HOS Study Guide (Strieb, Glenn, and Wherry, 1978).

7. CONCLUSIONS AND RECOMMENDATIONS

The principal conclusion to be drawn from the work documented in this report is that HOS is a suitable tool for description and simulation of aircraft pilot behavior. Control procedures can be expressed efficiently, modularly, and understandably. The physical characteristics of the crew-station can be represented quite effectively. Simulation outputs are readily analyzed from a variety of points of view using program components of the HOS system. Modifications to any aspects of a simulation can be made quickly and easily.

It is interesting, but somewhat incidental, that the results of the HOS-TCV simulations agree closely in several aspects with corresponding experimental data. More important, perhaps, is that the organization of HOS is conducive to the investigation of disagreements between simulation and experiment and to the formulation of appropriate revisions to simulation details. HOS enables the analyst to collect precise data on virtually any aspect of simulation performance and, through the HODAC analyses, to attribute output characteristics to specific features of procedures, functions, or input parameters.

Several probelms and deficiencies in the HOS-TCV simulations should be discussed for their implications for further work along this line. The difficulty in achieving effective pilot control over the aircraft was noted in the previous section. This problem represents a shortcoming in our understanding of pilot behavior rather than a limitation of HOS. It can be resolved by adaptation of results from other control modeling research to the HOS operator procedures, by iterative modifications to the control procedures to rectify specific control inadequacies, and by asking experienced pilots to critique the HOS procedures. All three of these lines could profitably be pursued in parallel with one another.

Another important deficiency in these simulations, also related to the adequacy of the control procedures, is that the simulations do not deal with aircraft attitude variables as distinct from aircraft motion vector variables. The aircraft attitude variables (heading, bank angle, pitch) describe the orientation of the aircraft while the motion vector variables (track angle, turn rate, and flight-path angle) describe how the aircraft is moving in space. Except for the relationship between bank angle and turn rate (for which an approximate aerodynamic formula was used), it was assumed that the aircraft moves exactly as it is oriented. That is, it was assumed that aircraft track angle is the same as aircraft heading and that flight-path angle is the same as pitch angle. This simplification was made primarily because it would have been significantly beyond the scope of the present effort to develop a simulation of the aircraft dynamics that incorporated a realistic model of the interactions between attitude and motion variables. As a consequence of this simplification, the pilot control procedures in the simulation do not reflect the ways that a pilot would use attitude information as distinct from motion vector information. While attention to these additional dimensions of system state information will complicate the task of developing realistic control procedures, it is clear that this undertaking is necessary if the behavior of real pilots is to be described.

While past HOS simulations for other man-machine systems have devoted roughly equal levels of effort to modeling operator and hardware processes, such large investments in hardware modeling have been warranted by the fact that alternative hardware simulators have generally not been available. Even when hardware models are available, the task of interfacing them with the HOS system is often sufficiently formidable that independent development of hardware models in the context of HOS is preferred. Indeed, the structure of HOS and the HOPROC language make the job of constructing hardware models much easier than with conventional programming languages.

However, in the case of the current simulation, the investment that would be required to expand the model of the TCV dynamics to include the effects of aircraft attitude variables and related factors of wind and turbulence on aircraft motion might be greater than the cost of interfacing HOS with an existing aircraft simulation program. It would be necessary to examine the capabilities, limitations, and configurational characteristics of available aircraft simulation programs before making a firm recommendation on this issue. In any case, it is highly desirable to improve on the current HOS aircraft dynamics model with respect to the factors of attitude and environmental influences before further refinements are made to the operator control procedures.

In summary, we recommend the following three stage effort:

(1) Enhance current model for aircraft performance, either by modification or replacement by another program, so that it represents the effects of wind, turbulence, and aircraft attitude on aircraft motion,

(2) Modify current pilot control procedures to produce realistic qualities of aircraft control, including pilot use of both aircraft attitude and aircraft motion variables,

(3) After the above recommendations are implemented, examine detailed visual dwell and link statistics for the HOS simulations, compare those statistics to corresponding oculometer data, and revise the pilot control procedures so as to improve the correspondence.

After these tasks are accomplished, the resulting HOS simulation program should provide useful insights into pilot control behavior and should constitute an effective tool for the evaluation of new and revised display and control design concepts.

APPENDIX A
HOS SIMULATION CODE

A. HOS SIMULATION CODE

Pages 63 through 96 present the simulation code for the pilot TCV system. The same code applies to both the VCWS and 3D-Auto control modes and to both the curved and straight-in approaches. Brief descriptions are offered for each section of inputs and for each procedure and function. Further general explanation of HOS simulation inputs is presented in the HOS Study Guide (Strieb, Glenn, and Wherry, 1978).

A.1 SYSTEM CARD

The SYSTEM card assigns a name to the simulation. In this case, the name is TEST---------TCV. The name is used as a header for all HOS output.

A.2 SETTING SECTION

This section lists the HOPROC names for all settings that can be assumed as values for discrete devices.

A.3 OSTATE SECTION

Operator states (o-states) are intended to provide a means by which the analyst can describe operator characteristics such as fatigue level and general motor performance rates and dynamically modify these parameters throughout the simulation. O-states have not yet been implemented in HOS. Thus, there are no specifications included in this section.

A.4 ARGUMENT SECTION

Arguments are general-purpose HOPROC variables that can be used to reference any HOPROC setting, device, or function. They can also be used to store numberic values. All arguments that are used in the simulation must be declared in the Argument Section.

A.5 DISPLAY SECTION AND CONTROL SECTION

All display and control instruments are declared in these sections. Listed first on each line is the name of the device which is generally the same as the name of the TCV device that the entry represents. In some cases, the names have been abbreviated. (HOPROC names must be uniquely defined by the first 20 characters in the name.) The second entry on each line indicates whether the device is discrete (if the entry is SETTINGS or MOMENTARY), positional (if the entry is COORDINATES), or continuous (if the entry is SCALE, blank, or anything in parentheses*). If the display is scaled, the scale factor follows; if it is discrete, the allowable settings follow. Some continuous devices have scale factors enclosed in parentheses because the scale factor is not a standard HOS scale factor. Devices are grouped according to the panel on which they appear. One group of variables that are not actually displayed quantities are included in the Display section. These variables are listed under the heading, STATE VARIABLES. They represent the actual location and speed of the aircraft and the simulation time when that data was last updated.

A.6 SYMBOL SECTION

Entries in the Symbol section are declared in the same basic format as used in the Display and Control sections. However, two new HOPROC conventions appear in this section. Both of these conventions relate to the fact that the HOPROC category of symbols refers to items which have several separate attributes, one of which is its location on the display panel (presumably a CRT screen). One special convention used in the Symbol section is that several entries grouped together represent the separate attributes of a symbol. Thus, AIRCRAFT-SYMBOL represents status of the aircraft symbol

*Entries in parentheses are disregarded by HAL, the HOS input processor.

on the EHSI and AIRCRAFT-POSITION represents the location of that symbol on the screen. The second special convention appearing in the Symbol section (but which can also be used in the Display and Control sections) is the hierarchical declaration of a device grouping. The numbers 4, 5 after the entry WAYPOINT indicate that WAYPOINT is a group title, that the four subsequent entry names (NAME, ALTITUDE, SPEED, and POSITION) are subgroup titles, and that there are five entries in each subgroup. HAL interprets this declaration group to indicate a total of 20 symbol names of the form:

WAYPOINT-1-NAME,...,WAYPOINT-5-NAME,...,WAYPOINT-1-POSITION,...,
WAYPOINT-5-POSITION .

It is assumed that entries in different subgroups, but with the same subgroup number, refer to separate attributes of the same symbol.

A.7 OPERATOR FUNCTIONS

HOS operator functions are written in a pseudo-FORTRAN. Functions are entered in the Operator Function section. Although the functions form a single subroutine program in HOS, each operator function is effectively treated as a separate subroutine. For readability, each operator function is identified by a FORTRAN comment card indicating the name of the function in quotes and parentheses. Each function is terminated by the appearance of the function name in quotes on the left side of a FORTRAN replacement statement (i.e., on the left side of an equal sign). HOPROC names that appear in quotes refer to the operator's estimated value for a device or function. HOPROC variables that are contained in carats (<...>) refer to HOS dictionary entry numbers. The function definitions are as follows:

- ABS-DIST-WPT-TO-CRV
  This function determines the absolute distance in feet between the current aircraft position and the nearest point on the curved trend vector as displayed on the EHSI.

- AC-ALTITUDE
  This function calculates the aircraft altitude from the barometric altimeter indicators for thousands and hundreds of feet altitude.

- AIRSPEED-CHECK
  This function represents a cross-check of the AIRSPEED-INDICATOR, MACH-INDICATOR, and GROUND-SPEED displays.

- ALTITUDE-CHECK
  This function cross-checks the aircraft altitude displayed on the barometric altimeter against the RADIO-ALTITUDE display on the EADI (if it is active) and checks both values against a calculated desired value.

- BROLLY-CONTROL
  This function indicates whether or not a control manipulation using the Brolly handles has been completed.

- BROLLY-STOP
  This function determines when the curvature of the EHSI curved trend vector is sufficiently close to its desired value so that rotational manipulation of the Brolly handles should be stopped.

- CALL-CHECKLIST-FLAPS
  This function represents the pilot action of calling for the Checklist to Flaps.

- CALL-FLAPS
  This function represents the pilot action of calling for a specific flap setting.

- CALL-LANDING-GEAR
  This function represents the pilot action of calling for the landing gear to be lowered.

- CALL-LAND-MODE
  This function represents the pilot action of calling for the copilot to turn the CRUISE-LAND-TST-KNOB on the EADI Mode Control Panel to the setting LAND and thus switch from MLS to ILS navigation and to enable a number of EADI display features for landing assistance.

- CAS-CHANGE
  This function represents the pilot's computation of the amount by which he wants to change the value of the CAS-ENG-DISPLAY.

- COURSE-CHANGE
  This function, which is executed as the pilot begins to navigate to a new waypoint, determines the heading change that is required. The result of this function is used as the rotational force to be applied to the Brolly handles.

- CURVED-ADJ-BANK
  This function determines whether the pilot should bank to the left or the right to move the curved trend vector closer to a waypoint.

- CURVED-ADJ-FORCE
  This function determines the force to be applied to the Brolly handles in making corrections to a turn toward a waypoint subsequent to the initiation of the turn.

- CURVE-TOL
  This function computes a tolerance for the distance between the curved trend vector and the waypoint it should intersect. The formula defines tolerance as a linear function of aircraft distance from the waypoint so that the tolerance is 1000 feet at a distance of 27,000 feet and 200 feet at a distance of 2000 feet.

- DELTA-CURVATURE
  This function determines the curvature differential for the curved trend vector at which termination of rotational force application on the Brolly handles should be started.

- DESIRED-CURVATURE
  This function determines the radius of curvature required to make the curved trend vector intersect the next waypoint.

- DH-CONDITION
  This function determines whether or not a missed approach should be executed when decision height is reached. If the glideslope or localizer exceed their limits by a factor of 2 or if the airspeed is outside of the limits for landing, then a missed approach will be selected.

- DH-CRIT
  This function modifies the criticality of the DH-ALTITUDE display in order to ensure that it is monitored when decision altitude is reached.

- DIST-PAST-WAYPOINT
  This function determines the distance of the aircraft from the previous waypoint. If the previous waypoint has not actually been passed yet, the value is negative.

- DIST-TO-WAYPOINT
  This function determines the distance from the aircraft position to the next waypoint.

- DIST-WPT-TO-CURVE
  This function determines the signed difference between the aircraft position and the nearest point on the curved trend vector. The sign of the difference indicates the direction of the error.

- FIRST-WAYPOINT
  This function establishes the designation number for the first waypoint to be navigated toward upon simulation initiation.

- FLARE-COND
  This is a dummy function which is used as the object of an operator procedure (TO MONITOR FLARE-COND) which determines when the pilot should perform the flare maneuver.

- FLARE-CRIT
  This function determines a criticality for the FLARE-COND function (and, hence, for the associated monitor procedure) in order to ensure that the flare maneuver will be performed at the appropriate time. The computed criticality increases linearly from 1 to 5 as the aircraft altitude decreases from 110 to 10 feet.

- FLY-TO-CRIT
  This function determines a criticality for the FLY-TO-WAYPOINT procedure which increases when the waypoint is neared so that control will be returned to FLY-TO-WAYPOINT which then initiates the APPROACH-WAYPOINT procedure.

- GAMMA-ADJ-PITCH
  This function determines the desired flight path angle to be assumed (one degree up or down from the current angle) in order to compensate for a GLIDE-SLOPE error.

- GAMMA-CHANGE
  This function determines the amount by which the COMMAND-GAMMA wedges must be changed to attain a new desired value.

- GAMMA-CHECK
  This function cross-checks the displays of flight path angle — COMMAND-GAMMA, GAMMA-WEDGES, and FPA-SEL-DISPLAY.

- GLIDE-SLOPE-CAPTURE
  This function determines whether a glide-slope adjusting maneuver should be ended (function value is positive) or not (function value is negative).

- GS-INT
  This function determines when the aircraft is within the horizontally defined region covered by the glide-slope beacon (assumed to be within 10^{0} of the prescribed localizer path).

- GS-INTERCEPT
  This function determines (for the straight-in approach) when the glide-slope is intercepted. As the glide-slope error approaches zero, the criticality of the glide-slope display is increased.

- GS-RANGE
  This function indicates aircraft range from the glide-slope beacon.

- HALF-LOCALIZER
  This function establishes the localizer value (half the initial value) at which a localizer adjusting turn should be reversed (i.e., the middle of the S-turn).

- ILS-INT
  This function determines when the aircraft is within the horizontal envelope of the ILS beacons (assumed to be within 10^{0} of the prescribed localizer path).

- ILS-RANGE
  This function indicates aircraft range from the ILS beacon.

- INITIAL-GLIDE-SLOPE
  This function defines the flight-path angle to be established by the pilot at the beginning of the simulation.

- INITIAL-GS-LIMITS
  This function defines the tolerance limits for glideslope to be established for the pilot at the beginning of the simulation.

- INITIAL-VALUES
  This function serves to initialize a diverse set of values for the simulation.

- LANDING-SPEED
  This function is used to compare the value of the AIRSPEED-INDICATOR against the desired, upper and lower values defined for this function.

- LAST-WAYPOINT
  This function determines the index number of the previous waypoint.

- LG-CALL
  This function indicates whether or not the pilot has yet called for lowering of the landing gear.

- LG-RANGE
  This function is used to compare the computed distance to touchdown (TD-DISTANCE) against the desired, upper and lower values for this function in order to determine when it is appropriate to call for lowering of the landing gear.

- LOC-ADJ-BANK
  This function determines the bank angle to be assumed in a turn to compensate for a localizer error.

- LOC-ADJ-COMPLETE
  This function determines when a localizer adjusting maneuver is complete and it is time to roll out of the final segment of the S-turn.

- LOC-ADJ-FORCE
  This function determines the rotational force to be applied to the Brolly handles in order to perform a turn to compensate for a localizer error.

- LOC-ADJ-MIDPOINT
  This function determines when the midpoint in a localizer adjusting S-turn has been reached and it is appropriate to reverse the aircraft bank angle.

- LOC-ADJ-RETURN
  This function determines the rotational force to be applied to the Brolly handles to roll out of a localizer-compensating turn.

- LOC-ADJ-WAIT
  This function indicates when the ROLL-INDICATOR has reached the value desired for a localizer-compensating turn.

- LOC-RANGE
  This function is used to determine when the aircraft is within the range of the localizer beacon.

- LOC-RETURN-BANK
  This function defines the desired bank angle for the second segment of a localizer adjusting S-turn.

- MIDDLE-BEACON-MISS
  This function indicates when the pilot should conclude that he has failed to intercept the middle marker.

- MM-INT
  This function indicates whether or not the pilot should expect to encounter a middle marker on his current approach.

- MM-RANGE
  This function is used to determine when the aircraft should be within range of the middle marker beacon.

- NEW-FLAPS
  This function determines the current desired flap setting.

- NEW-MAP-SCALE
  This function determines the current desired map scale.

- OLD-COMMAND-GAMMA
  This function defines the COMMAND-GAMMA value to which the pilot should return after performing a maneuver to compensate for a glide-slope error.

- OLD-GLIDE-SLOPE
  This function establishes the initial glideslope value to be used for reference in the glideslope adjusting maneuver.

- OM-INT
  This function indicates whether or not the pilot should expect to encounter an outer marker on his current approach.

- OM-RANGE
  This function is used to determine when the aircraft should be within range of the outer marker beacon.

- OUTER-BEACON-MISS
  This function indicates when the pilot should conclude that he has failed to intercept the outer marker.

- RESET-GAMMA
  This function is used to reset the value of COMMAND-GAMMA to the value it had prior to a just-completed maneuver to compensate for a glide-slope error.

- REVIEW-MONITORS
  This is a dummy function that serves as the object of a monitoring procedure (TO MONITOR REVIEW-MONITORS) that determines which devices and functions should currently be monitored.

- ROLL-OUT-FORCE
  This function determines the rotational force to be applied to the Brolly handles to roll out of a turn.

- TD-DISTANCE
  This function computes the distance of the aircraft from its desired touchdown position.

- TRACK-CHECK
  This function cross-checks the displays of aircraft track angle -- TRACK-BOX, TRACK-ANGLE, and TKA-SEL-DISPLAY.

- TRK-CORR-FORCE
  This function determines the rotational force to be applied to the Brolly handles to execute a turn that should compensate for a track angle error.

- TRK-CORR-STOP
  This function determines when it is appropriate to terminate a turn that compensates for a track angle error.

- TRK-ERR-TO-WPT
  This function computes the heading error between the current aircraft track angle and the track angle required to reach the next waypoint.

- TRK-TO-WPT
  This function determines the track angle required for the aircraft to reach the next waypoint.

- VERT-SPEED-CHECK
  This function cross-checks the displayed vertical speed of the aircraft (from the VSI) against an estimate of vertical speed computed from the values of COMMAND-GAMMA and AIRSPEED-INDICATOR.

- WAYPOINT-ALT-CHECK
  This function determines whether or not the current flight path will take the aircraft acceptably close to the altitude desired for the next waypoint.

- WAYPOINT-CLOSE
  This function determines the distance from the next waypoint when it is appropriate to perform the APPROACH-WAYPOINT procedure.

- WAYPOINT-GS-CHECK
  This function checks on the glide-slope error at waypoint (required to be less than two dots).

- WAYPOINT-LOC-CHECK
  This function checks on the localizer error at a waypoint (required to be less than two dots).

- WAYPOINT-SPEED-CHECK
  This function checks on the airspeed at a waypoint (required to be within two percent of the prescribed value).

A.8 HARDWARE FUNCTIONS

The introduction to Operator Functions presented above applies also to Hardware Functions with the single exception that quoted HOPROC variables refer to the actual simulation value of the referenced device or function rather than the operator's estimate for that value.

- AUTO-BROLLY-ROLL
  This function simulates the operation of the autopilot in 3D-Auto control mode by establishing appropriate Brolly handle force inputs.

- CAS-END
  This function terminates a change in the value of the CAS-ENG-DISPLAY.

- CAS-RATE
  This function determines the rate of change in the value of the CAS-ENG-DISPLAY corresponding to a manipulation of the CAS-ENG-KNOB.

- COMMAND-GAMMA-RATE
  This function determines the rate of change in the COMMAND-GAMMA wedges corresponding to a longitudinal manipulation of the Brolly handles.

- NEW-BANK
  This function determines the current aircraft bank angle and curved trend vector radius based on the rotational force applied to the Brolly handles.

- NEW-COMMAND-GAMMA
  This function determines the current value for the COMMAND-GAMMA wedges based on the longitudinal force applied to the Brolly handles.

- NEW-GAMMA
  This function determines the current value and rate of change for the GAMMA-WEDGES based on the value of the COMMAND-GAMMA wedges.

- NEW-LOCATION
  This function computes current values for aircraft location, altitude, vertical speed, ground speed, and track angle according to all flight path parameters.

- NEW-SPEED
  This function determines the current value and rate of change of airspeed according to the value of the CAS-ENG-DISPLAY.

- PATH-ERRORS
  This function determines glide-slope and localizer errors as a function of navigation mode (ILS or MLS) and desired path geometry.

- SYMBOL-SCALE
  This function repositions symbols on the EHSI when the map scale is altered.

A.9 HARDWARE PROCEDURES

The Hardware Procedures serve in this simulation to coordinate the execution of the Hardware Functions which perform the primary mathematical modeling functions. Each procedure is introduced by a DEFINE THE PROCEDURE... statement. For procedures that represent the consequences of control actuations, the introductory statement continues with the phrase TO SIMULATE followed by the HOPROC name of the control. Statement labels in these control simulation procedures are in the left margin followed by a colon and they indicate whether each line is to be executed at the beginning of the manipulation (START), at the completion of the manipulation (END), or throughout the course of the manipulation after it is started (MIDEND).

- PROCEDURE AC-UPDATE
  This procedure is executed periodically throughout the simulation at a rate of two to four times every simulation second. It directs the computation of the Hardware Functions that serve to update aircraft location and movement variables.

- PROCEDURE TO SIMULATE BROLLY-PITCH
  This procedure simulates the effects of a longitudinal manipulation of the Brolly handles.

- PROCEDURE TO SIMULATE CAS-ENG-KNOB
  This procedure simulates the movement of the CAS-ENG-KNOB.

- PROCEDURE TO SIMULATE MAP-SCALES
  This procedure simulates the effects of a change in the value of the MAP-SCALES switch.

- PROCEDURE TO START-SIMULATION
  This procedure is used with a contrived START-SIMULATION switch to initiate the periodic execution of the AC-UPDATE procedure.

- PROCEDURE TO SIMULATE VEL-CWS-SWITCH
  This procedure simulates the effects of operation of the VEL-CWS-SWITCH which activates the VCWS control mode.

A.10 OPERATOR PROCEDURES

In this simulation, there are three special types of procedures in addition to standard operator procedures. One special procedure is called MISSION. It is the executive procedure of the simulation and the first procedure to be executed. The two other special types of procedure are MONITOR and ADJUST procedures (as indicated by the relevant term after the introductory phrase, DEFINE THE PROCEDURE TO...). These types of procedure are given special priority whenever a new procedure is selected by the HOS multiplexer. The only difference between MONITOR and ADJUST procedures is that ADJUST procedures are removed from the active procedures list when an END statement (implicit or explicit) is encountered whereas MONITOR procedures remain active to be executed again from the beginning. MONITOR procedures are only terminated when explicit END MONITORING statements are encountered. Statement labels

appear in the left margin of Operator Procedure statements just as in the Hardware Procedures section. However, in the Operator Procedures section, statement labels are used only for explicit internal transfer of control (i.e., via GO TO... statements).

- PROCEDURE TO MONITOR AIRSPEED-CHECK
  This procedure directs the cross-check of indicators of airspeed and the determination whether a new flap setting is required.

- PROCEDURE TO MONITOR ALTITUDE-CHECK
  This procedure directs the cross-check of indicators of aircraft altitude.

- PROCEDURE TO APPROACH-WAYPOINT
  This procedure is executed when the aircraft is fairly close to its next waypoint. The pilot checks that the desired conditions at the waypoint have been attained (if not, he performs the procedure, NOTIFY-ATC) and rolls out of any turn in progress.

- PROCEDURE TO ADJUST BROLLY-ROLL
  This procedure directs the initial banking of the aircraft to make the curved trend vector intersect the next waypoint (on the EHSI display).

- PROCEDURE TO ADJUST CAS-ENG-DISPLAY
  This procedure directs the adjustment of the CAS-ENG-DISPLAY to its desired value.

- PROCEDURE TO MONITOR CALL-FLAPS
  This procedure monitors the FLAP-INDICATOR to ensure that the flaps are set at the desired value.

- PROCEDURE TO ADJUST THE COMMAND-GAMMA
  This procedure adjusts the COMMAND-GAMMA wedges to their desired value.

- PROCEDURE TO ADJUST DH-ALTITUDE
  This procedure monitors for the decision altitude condition (if DH-ALTITUDE is ON or RADIO-ALTITUDE is less than 180 feet) and determines whether or not a missed approach must be executed.

- PROCEDURE TO ADJUST FLARE-COND

  This procedure monitors RADIO-ALTITUDE to determine when the flare maneuver must be performed. As the altitude approaches 50 feet, the criticality of the monitoring operation is increased. As soon as the altitude is less that 65 feet, the pilot pulls the THROTTLE-LEVER back to IDLE and raises the nose of the aircraft by setting the COMMAND-GAMMA wedges to five degrees.

- PROCEDURE TO FLY-TO-WAYPOINT

  This procedure manages the major functions involved in flying from one waypoint to the next. If a turn is called for, the TURN-TO-WAYPOINT procedure is invoked. If a straight path is appropriate, then the STRAIGHT-VECTOR is monitored. Airspeed is adjusted to the speed called for at the next waypoint. When the waypoint is neared (as defined by the Operator Function, WAYPOINT-CLOSE), the procedure, APPROACH-WAYPOINT, is executed.

- PROCEDURE TO MONITOR GAMMA-CHECK

  This procedure directs the cross-check of indicators of flight path angle.

- PROCEDURE TO MONITOR GLIDE-SLOPE

  This procedure monitors the value displayed on the GLIDE-SLOPE indicator and directs a corrective adjustment whenever the value exceeds prescribed limits. If the RADIO-ALTITUDE indicates that the aircraft is below 100 feet, no corrective adjustment is initiated.

- PROCEDURE TO ADJUST GLIDE-SLOPE-CAPTURE

  This procedure monitors the function GLIDE-SLOPE-CAPTURE in order to delay the change to the desired flight-path angle until the glideslope value is near zero.

- PROCEDURE TO ADJUST GS-INTERCEPT

  This procedure directs the maneuver to capture the GLIDE-SLOPE in the straight-in approach.

- PROCEDURE TO MONITOR LOCALIZER

  This procedure monitors the value displayed on the LOCALIZER indicator and directs a corrective adjustment whenever the value exceeds prescribed limits. Alternate adjustment procedures are specified depending on whether or not the aircraft is in the process of turning when the error is detected.

- PROCEDURE TO MONITOR MAP-SCALE
  This procedure monitors the scale on the EHSI display to ensure that all remaining waypoints are displayed using the minimum possible MAP-SCALE setting.

- PROCEDURE TO MONITOR MIDDLE-BEACON-LIGHT
  This procedure monitors for aircraft passage over the middle marker.

- PROCEDURE MISSED-APPROACH
  This procedure represents the action taken by the pilot when the decision is negative at decision-altitude.

- MISSION
  This procedure initializes the simulation and manages the FLY-TO-WAYPOINT procedure.

- PROCEDURE TO NOTIFY-ATC
  This procedure represents the action taken by the pilot when a system malfunction is detected.

- PROCEDURE TO MONITOR OUTER-BEACON-LIGHT
  This procedure monitors for aircraft passage over the outer marker.

- PROCEDURE TO REVIEW-MONITORS
  This procedure checks on changing conditions to determine when new monitoring procedures should be invoked.

- PROCEDURE TO ADJUST ROLL-INDICATOR
  This procedure is used in a turn maneuver to cause the pilot to wait for a desired ROLL-INDICATOR value to be attained before proceeding with the maneuver.

- PROCEDURE TO ROLL-OUT
  This procedure directs the return of the aircraft to level flight.

- PROCEDURE TO MONITOR STRAIGHT-VECTOR
  This procedure monitors the STRAIGHT-VECTOR and directs adjustment to aircraft heading when the next waypoint is not sufficiently close to the vector.

- PROCEDURE TO MONITOR TRACK-CHECK
  This procedure directs the cross-check of indicators of aircraft heading.

- PROCEDURE TO TURN-TO-WAYPOINT
  This procedure directs the performance of a sweeping turn from one waypoint to the next. An initial bank angle is assumed to bring the curved trend vector near the next waypoint symbol on the EHSI. Corrective adjustments are made as necessary throughout the course of the turn by return of control to statement label CYCLE. At approximately the same time that the APPROACH-WAYPOINT procedure is initiated, this procedure is terminated.

- PROCEDURE TO MONITOR VERT-SPEED-CHECK
  This procedure directs the cross-check of independent indicators of aircraft vertical speed.

```
SYSTEM                    MASTER-----TCV
SETTING SECTION
      ON  OFF
      F0 F1 F5 F15 F25 F30 F40
      RIGHT LEFT STRAIGHT
      M1  M2
      M4  M8
      M16  M32
      AUTO  MANUAL
      CRUISE  LAND  TEST
      IDLE
      MM  OM
      QUARY  RAPID  NORMA  DUBIL  GPIUL
      TRACK  NORTH

OSTATE SECTION
ARGUMENT SECTION
      NEXT-WAYPOINT
      TOLERANCE
      REFERENCE-POSITION
      ST-VECT-BEING-ADJ
      LOC-BEING-ADJUSTED
DISPLAY SECTION

      (CENTER INSTRUMENT PANEL)

      CAS-ENG-DISPLAY          SCALE       KNOTS
      ALT-ENG-DISPLAY          SCALE       FEET
      FPA-SEL-DISPLAY          SCALE       DEGREES
      TKA-SEL-DISPLAY          SCALE       DEGREES
      VEL-CWS-LIGHT            SETTINGS    ON  OFF.
      AUTO-LIGHT               SETTINGS    ON  OFF.
      HOR-PATH-LIGHT           SETTINGS    ON  OFF.
      VERT-PATH-LIGHT          SETTINGS    ON  OFF.
      SPEED-BRAKES-ARMED       SETTINGS    ON  OFF.
      FLAP-INDICATOR           SETTINGS    F0 F1 F5 F15 F25 F30 F40.
      DONT-ARM-SB-ANN          SETTINGS    ON  OFF.
      LANDING-GEAR-ANN         SETTINGS    ON  OFF.
      CAS-ENG-LIGHT            SETTINGS    ON  OFF.
      ALT-ENG-LIGHT            SETTINGS    ON  OFF.
      FPA-SEL-LIGHT            SETTINGS    ON  OFF.
      TKA-SEL-LIGHT            SETTINGS    ON  OFF.

      (EADI DISPLAY COMPONENTS)

      EADI                     COORDINATES MILES
      ROLL-INDICATOR           SCALE       DEGREES
      LOCALIZER               (SCALE       DOTS)
      GLIDE-SLOPE             (SCALE       DOTS)
```

```
RADIO-ALTITUDE          SCALE       FEET
AIRCRAFT-PITCH          SCALE       DEGREES
DH-ALTITUDE             SETTINGS    ON  OFF.
GAMMA-WEDGES            SCALE       DEGREES
COMMAND-GAMMA           SCALE       DEGREES
FLIGHT-PATH-ACC         (SCALE      KNOTS-PER-MIN)
HORIZON                 SETTINGS    ON.
PITCH-REF-LINE          SCALE       DEGREES
RUNWAY-LINE-INTRCPT     SCALE       DEGREES
RUNWAY-LINE-ANGLE       SCALE       DEGREES
TRACK-POINTER           SCALE       DEGREES

(EADI MODE CONTROL PANEL)

DH-REF-DISPLAY          SCALE       FEET
PITCH-REF-DISPLAY       SCALE       DEGREES

(EHSI DISPLAY COMPONENTS)

EHSI                    COORDINATES MILES
TRACK-BOX               SCALE       DEGREES
TRACK-BUG               SCALE       DEGREES
STRAIGHT-VECTOR         (SCALE      DEGREES)
CURVED-VECTOR-RADIUS    (SCALE      NM)
CURVED-VECTOR-DIR       SETTINGS    LEFT RIGHT STRAIGHT.
MAP-SCALE               SETTINGS    M1 M2 M4 M8 M16 M32.
GROUND-SPEED            SCALE       KNOTS
WIND-DIRECTION          SCALE       DEGREES
WIND-VELOCITY           SCALE       KNOTS


(NCDU DISPLAY COMPONENTS)

NCDU                    COORDINATES MILES
ALTITUDE-NCDU           SCALE       FEET
ALTITUDE-ERROR          SCALE       FEET
FLIGHT-PATH-ERROR       SCALE       DEGREES
TRACK-ANGLE             SCALE       DEGREES
TRACK-ANGLE-ERROR       SCALE       DEGREES
TRK-ERR-DIRECTION       SETTINGS    LEFT  RIGHT.
CROSS-TRACK-ERROR       SCALE       MILES
CR-TRK-ERR-DIRECT       SETTINGS    LEFT RIGHT.
GROUND-SPEED-NCDU       SCALE       KNOTS

(PILOT'S INSTRUMENT PANEL)

BARO-ALTIMETER-THOU     (SCALE      KFEET)
BARO-ALTIMETER-HUND     (SCALE      CFEET)
VSI                     (SCALE      KFEET-PER-MIN)
```

```
      MACH-INDICATOR          (SCALE      MACH)
      AIRSPEED-INDICATOR       SCALE      KNOTS
      OUTER-BEACON-LIGHT       SETTINGS   ON  OFF.
      MIDDLE-BEACON-LIGHT      SETTINGS   ON  OFF.

      (STATE VARIABLES)

      SPEED
      XAC
      YAC
      ALTITUDE
      TACUP                    (TIME OF AC POSITION UPDATE)
CONTROL SECTION

      (CENTER INSTRUMENT PANEL)

      VEL-CWS-SWITCH           MOMENTARY
      AUTO-SWITCH              MOMENTARY
      HOR-PATH-SWITCH          MOMENTARY
      VERT-PATH-SWITCH         MOMENTARY

      (CONTROL STAND)

      SPEED-BRAKE-LEVER        SETTINGS   ON  OFF.
      THROTTLE-LEVER           SETTINGS   ON  IDLE.

      (EADI MODE CONTROL PANEL)

      DH-REF-KNOB              SCALE      DEGREES
      PITCH-REF-KNOB           SCALE      DEGREES
      AUTO-MANUAL-LIGHT        SETTINGS   AUTO  MANUAL.
      CRUISE-LAND-TST-KNOB     SETTINGS   CRUISE  LAND  TEST.
      AUTO-MANUAL-SWITCH       MOMENTARY

      (MFD MODE PANEL)

      WPT-ALT                  MOMENTARY
      TREND-VECTOR             MOMENTARY
      MAP-SCALES               SETTINGS   M1 M2 M4 M8 M16 M32.
      TRACK-UP-SWITCH          SETTINGS   TRACK  NORTH  TEST.


      (PILOT'S INSTRUMENT PANEL)

      BROLLY-PITCH             (SCALE     POUNDS)
      BROLLY-ROLL              (SCALE     POUNDS)
      LEFT-BROLLY-HANDLE       (SCALE     POUNDS)
      RIGHT-BROLLY-HANDLE      (SCALE     POUNDS)
      CAS-ENG-KNOB              SCALE     DEGREES
      ALT-ENG-KNOB              SCALE     DEGREES
      FPA-SEL-KNOB              SCALE     DEGREES
```

```
      TKA-SEL-KNOB            SCALE       DEGREES
      START-SIMULATION        SETTINGS    ON OFF.


SYMBOL SECTION
      AIRCRAFT-SYMBOL         SETTINGS    ON.
      AIRCRAFT-POSITION       COORDINATES FEET
      WAYPOINT                4,5
         NAME                 SETTINGS    QUARY RAPID NORMA DUBIL GPIUL.
         ALTITUDE             SCALE       FEET
         SPEED                SCALE       KNOTS
         POSITION             COORDINATES FEET
      OUTER-MARKER-NAME       SETTINGS    OM  OFF.
      OUTR-MKR-POSITION       COORDINATES MILES
      MIDDLE-MARKER-NAME      SETTINGS    MM  OFF.
      MID-MKR-POSITION        COORDINATES MILES
      RUNWAY-1000FT-MARK      SETTINGS    ON  OFF.
      RNWY-1000FT-POSITION    COORDINATES DEGREES
OPERATOR FUNCTIONS
      DIMENSION FLPSPD(7),RSTMAP(3)
      DATA FLPSPD/600.,210.,190.,170.,150.,140.,130./,
     + RSTMAP/60000.,30000.,15000./
      GO TO 10000
9000  CONTINUE
C
C     ("ABS-DIST-WPT-TO-CRV")
C
      "ABS-DIST-WPT-TO-CRV"=ABS("DIST-WPT-TO-CURVE")
C
C     ("ABS-TRK-ERR-TO-WPT")
C
      "ABS-TRK-ERR-TO-WPT"=ABS("TRK-ERR-TO-WPT")
C
C     ("AC-ALTITUDE")
C
      THOU="BARO-ALTIMETER-THOU"
      HUND="BARO-ALTIMETER-HUND"
      ITHOU=THOU+.5
      "AC-ALTITUDE"=1000.*ITHOU+100*HUND
C
C     ("AIRSPEED-CHECK")
C
      AS="AIRSPEED-INDICATOR"
      AM="MACH-INDICATOR"*600.
      GS="GROUND-SPEED"
      WS="WIND-VELOCITY"
      XRES=1.
      IF(ABS(AS-AM).GT.(.1*AS)) XRES=-1.
      IF(AS.LT.(.9*(GS-WS)).OR.AS.GT.(1.1*(GS+WS))) XRES=-1.
      "AIRSPEED-CHECK"=XRES
```

```
C
C     ("ALTITUDE-CHECK")
C
      ALT="AC-ALTITUDE"
      DGAM="COMMAND-GAMMA"*.01745
      RALT=EST(<RADIO-ALTITUDE>)
      IF(STATE(<RADIO-ALTITUDE>).EQ.0.) RALT=ALT
      DST="DIST-TO-WAYPOINT"
      WA="WAYPOINT-ALTITUDE"
      AED="ALT-ENG-DISPLAY"
      DESALT=WA-DST*TAN(DGAM)
      IF("CRUISE-LAND-TST-KNOB".EQ.<LAND>)DESALT=AMIN1(WA+DST*.0524,
     +  1510.)
      XMAX=AMAX1(ALT,RALT,AED,DESALT)
      XMIN=AMIN1(ALT,RALT,AED,DESALT)
      RANGE=XMAX-XMIN
      AC=1.
      IF(RANGE.GT.200.) AC=-1.
      "ALTITUDE-CHECK"=AC
C
C     ("AUTO-CURVE-TOL")
C
      "AUTO-CURVE-TOL"="CURVE-TOL"*2.
C
C     ("BROLLY-CONTROL")
C
      T=TFREE(4)-STIME
      BC=-1.
      IF(T.GT.0.)BC=1.
      "BROLLY-CONTROL"=BC
C
C     ("BROLLY-STOP")
C
      BSTOP=0.
      ICVD="CURVED-VECTOR-DIR"
      INC=1
      IF(ICVD.EQ.<LEFT>) INC=-1
      BR="BROLLY-ROLL"
      R="CURVED-VECTOR-RADIUS"
      DESRC=EST(<DESIRED-CURVATURE>)
      DELTAR=EST(<DELTA-CURVATURE>)
      IF(BR*INC.LT.0.) GO TO 90
C     ROLL IS INCREASING
      IF(R.LE.(DESRC+DELTAR)) BSTOP=1.
      GO TO 100
90    CONTINUE
C     ROLL IS DECREASING
      IF(R.GE.(DESRC-DELTAR)) BSTOP=1.
100   CONTINUE
      "BROLLY-STOP"=BSTOP
```

```
C
C     ("CALL-CHECKLIST-FLAPS")
C
      "CALL-CHECKLIST-FLAPS"=0.
C
C     ("CALL-FLAPS")
C
      ACTUAL(<FLAP-INDICATOR>)=DESIRE(<FLAP-INDICATOR>)
      "CALL-FLAPS"=DESIRE(<FLAP-INDICATOR>)
C
C     ("CALL-LANDING-GEAR")
C
      DESIRE(<LG-CALL>)=-1.
      "CALL-LANDING-GEAR"=0.
C
C     ("CALL-LAND-MODE")
C
      ACTUAL(<CRUISE-LAND-TST-KNOB>)=<LAND>
      STATE(<GLIDE-SLOPE>)=1.
      STATE(<LOCALIZER>)=1.
      "CALL-LAND-MODE"=0.
C
C     ("CAS-CHANGE")
C
      SCALE=1.
      IND=<CAS-ENG-DISPLAY>
      DELTA=DESIRE(IND)-EST(IND)
      CHNG=DELTA/SCALE
      PRES=EST(<CAS-ENG-KNOB>)
      "CAS-CHANGE"=PRES+CHNG
C
C     ("COURSE-CHANGE")
C
      WPT="WAYPOINT-POSITION"
      AC="AIRCRAFT-POSITION"
      XWPT=XVALUE(WPT)
      YWPT=YVALUE(WPT)
      XAC=XVALUE(AC)
      YAC=YVALUE(AC)
      DX=XWPT-XAC
      DY=YWPT-YAC
      DST=SQRT(DX*DX+DY*DY)
      TRK=ACOS(DY/DST)*57.3
      IF(DX.LT.0.) TRK=360.-TRK
      TA="TRACK-BOX"
      TRN=TRK-TA
      IF(TRN.LT.-180.) TRN=360.+TRN
      IF(TRN.GT.180.) TRN=360.-TRN
      ATRN=ABS(TRN)
      IF(ATRN.LT.20.) TRN=0.
```

```
      IF(TRN.GT.0.) TRN=1.
      IF(TRN.LT.0.) TRN=-1.
      IF(ATRN.GT.30.) TRN=TRN*2.
      "COURSE-CHANGE"=TRN
C
C     ("CURVED-ADJ-BANK")
C
      DC="DESIRED-CURVATURE"
      TTW="TRK-TO-WPT"
      TA=EST(<TRACK-BOX>)
      OFFSET=180.-TTW
      TA=TA+OFFSET
      IF(TA.LT.0.)TA=TA+360.
      IF(TA.GT.360.)TA=TA-360.
      TURN=1.
      IF(TA.GT.180.)TURN=-1.
      S=EST(<AIRSPEED-INDICATOR>)*1.688
      DB=TURN*ATAN(S*S/(32.*DC))*57.3
      CAB=DB-"ROLL-INDICATOR"
      "CURVED-ADJ-BANK"=CAB
C
C     ("CURVED-ADJ-FORCE")
C
      CAB=EST(<CURVED-ADJ-BANK>)
      ACAB=ABS(CAB)
      CAF=.095*ACAB+.105
      CAF=AMAX1(.2,AMIN1(2.,CAF))
      CAF=CAF*CAB/ACAB
      "CURVED-ADJ-FORCE"=CAF
C
C     ("CURVE-TOL")
C
      D="DIST-TO-WAYPOINT"
      "CURVE-TOL"=.032*D+136.
C
C     ("DELTA-CURVATURE")
C
      IBR=<BROLLY-ROLL>
      BR=EST(IBR)*5.
      S=EST(<AIRSPEED-INDICATOR>)*1.688
      SNT=SIN(ATAN(S*S/(32.*EST(<DESIRED-CURVATURE>))))
      RR=ABS(S*S*BR*.01745/(32.*SNT*SNT))
      IM=MODEL(IBR)
      F=PARA(IM,8)
      DC=.3*RR*BR/F
      WRITE(6,8002) DC,BR,S,SNT,RR,F
8002  FORMAT(34HDELTA CURV. -- DC,BR,S,SNT,RR,F = ,6G14.5)
      "DELTA-CURVATURE"=DC
```

```
C
C     ("DESIRED-CURVATURE")
C
      TA="TRACK-BOX"/57.3
      AC="AIRCRAFT-POSITION"
      WPT="WAYPOINT-POSITION"
      XAC=XVALUE(AC)
      YAC=YVALUE(AC)
      XWPT=XVALUE(WPT)
      YWPT=YVALUE(WPT)
      DX=XWPT-XAC
      DY=YWPT-YAC
      DST=SQRT(DX*DX+DY*DY)
      ANG=ACOS(DY/DST)
      IF(DX.LT.0.) ANG=6.2832-ANG
      DANG=ANG-TA
      SD=SIN(DANG)
      DESRC=1E300
      IF(SD.NE.0.) DESRC=ABS(DST/(2.*SD))
      WRITE(6,8001) DESRC,DST,DANG
8001  FORMAT(31HDES. CURV. -- DESRC,DST,DANG = ,3G14.5)
      "DESIRED-CURVATURE"=DESRC
C
C     ("DH-CONDITION")
C
      GS="GLIDE-SLOPE"
      XLOC="LOCALIZER"
      XLS="LANDING-SPEED"
      SMAX=UPPER(<LANDING-SPEED>)
      SMIN=LOWER(<LANDING-SPEED>)
      DGS=UPPER(<GLIDE-SLOPE>)
      DLOC=UPPER(<LOCALIZER>)
      GS=ABS(GS)
      XLOC=ABS(XLOC)
      DHC=1.
      IF(GS.GT.2.*DGS.OR.XLOC.GT.2.*DLOC) DHC=-1.
      IF(XLS.LT.SMIN.OR.XLS.GT.SMAX) DHC=-1.
      "DH-CONDITION"=DHC
C
C     ("DH-CRIT")
C
      ALT="RADIO-ALTITUDE"
      D="DIST-TO-WAYPOINT"
      XALT=1.
      XD=1.
      IF(ALT.LT.245.)XALT=XALT+AMIN1((2.45-ALT)/20.,5.)
      IF(D.LT.4700.)XD=XD+AMIN1((4700.-D)/390.,5.)
      XCRIT=AMAX1(XD,XALT)*1.4
      HOSZC(<DH-ALTITUDE>)=PACKY(<DH-ALTITUDE>,XCRIT)
      "DH-CRIT"=XCRIT
```

```
C
C     ("DIST-PAST-WAYPOINT")
C
      XDUM="LAST-WAYPOINT"
      WPT="REFERENCE-POSITION"
      XWPT=XVALUE(WPT)
      YWPT=YVALUE(WPT)
      AS="AIRCRAFT-POSITION"
      XC=XVALUE(AS)
      YC=YVALUE(AS)
      D=DIST(XC,YC,0.,XWPT,YWPT,0.)
      TA=ACTUAL(<TRACK-BOX>)/57.3
      XV=SIN(TA)
      YV=COS(TA)
      TIM=XV*(XWPT-XC)+YV*(YWPT-YC)
      IF(TIM.GT.0.)D=-D
      "DIST-PAST-WAYPOINT"=D
C
C     ("DIST-TO-WAYPOINT")
C
      AS="AIRCRAFT-POSITION"
      XC=XVALUE(AS)
      YC=YVALUE(AS)
      WPT="WAYPOINT-POSITION"
      XWPT=XVALUE(WPT)
      YWPT=YVALUE(WPT)
      D=DIST(XC,YC,0.,XWPT,YWPT,0.)
      "DIST-TO-WAYPOINT"=D
C
C     ("DIST-WPT-TO-CURVE")
C
      TA="TRACK-BOX"/57.3
      AC="AIRCRAFT-POSITION"
      WPT="WAYPOINT-POSITION"
      R="CURVED-VECTOR-RADIUS"
      D="CURVED-VECTOR-DIR"
      DIR=0.
C     FIND CENTER OF CURVED-VECTOR CIRCLE (XCTR,YCTR)
      IF(D.EQ.<RIGHT>) DIR=1.
      IF(D.EQ.<LEFT>) DIR=-1.
      XAC=XVALUE(AC)
      YAC=YVALUE(AC)
      XWPT=XVALUE(WPT)
      YWPT=YVALUE(WPT)
      DD=0.
      IF(R.GT.1E100) GO TO 290
      DTW=DIST(XAC,YAC,0.,XWPT,YWPT,0.)
      IF(DTW.LT.2000.) GO TO 300
      XCTR=XAC+DIR*R*COS(TA)
      YCTR=YAC-DIR*R*SIN(TA)
C     FIND DISTANCE FROM CIRCLE CENTER TO WAYPOINT(DD)
```

```
      DX=XWPT-XCTR
      DY=YWPT-YCTR
      DD=SQRT(DX*DX+DY*DY)
      DD=DD-R
      GO TO 300
290   CONTINUE
C     FIND DISTANCE FROM STRAIGHT LINE TO WAYPOINT
      DST=SQRT((XWPT-XAC)**2+(YWPT-YAC)**2)
      ANG=ACOS((YWPT-YAC)/DST)*57.3
      IF((XWPT-XAC).LT.0.)ANG=360.-ANG
      OFFSET=180.-TA
      ANG=ANG+OFFSET
      IF(ANG.LT.0.)ANG=ANG+360
      IF(ANG.GT.360.)ANG=ANG-360.
      ANG=ANG-180.
      DD=DST*SIN(ANG/57.3)
300   CONTINUE
      "DIST-WPT-TO-CURVE"=DD
C
C     ("FIRST-WAYPOINT")

L


C
      CALL LPTAPE(1,STDUM,IDUM)
      NW=<NEXT-WAYPOINT>
      FW=EST(<FIRST-WAYPOINT>)
      CALL DUM(NW,FW)
      "FIRST-WAYPOINT"=FW
C
C     ("FLARE-COND")
C
      "FLARE-COND"=0.
C
C     ("FLARE-CRIT")
C
      ALT="RADIO-ALTITUDE"
      XALT=1.
      IF(ALT.LT.110.)XALT=XALT+AMIN1((110.-ALT)/20.,5.)
      XCRIT=XALT*1.4
      HOSZC(<FLARE-COND>)=PACKY(<FLARE-COND>,XCRIT)
      "FLARE-CRIT"=XCRIT
C
C     ("FLY-TO-CRIT")
C
      AS="AIRCRAFT-POSITION"
      XC=XVALUE(AS)
      YC=YVALUE(AS)
      WPT="WAYPOINT-POSITION"
      XWPT=XVALUE(WPT)
      YWPT=YVALUE(WPT)
```

```
      D=DIST(XC,YC,0.,XWPT,YWPT,0.)
      CR=1.5
      NW="NEXT-WAYPOINT"
      IF(D.LE.4000)CR=1.7
      IF(NW.EQ.5)CR=1.5
      IF(D.LE.3000)CR=1.9
      IF(D.LE.2000)CR=2.0
      "FLY-TO-CRIT"=CR
C
C     ("GAMMA-ADJ-PITCH")
C
      XGS="GLIDE-SLOPE"
      DES=DESIRE(<COMMAND-GAMMA>)
      V1=1.
      XGAM=DES*SIGN(V1,XGS)
      "GAMMA-ADJ-PITCH"=XGAM
C
C     ("GAMMA-CHANGE")
C
      X="COMMAND-GAMMA"
      Y=DESIRE(<COMMAND-GAMMA>)-X
      UP=UPPER(<COMMAND-GAMMA>)
      XL= LOWER(<COMMAND-GAMMA>)
      IF(X.GE.XL.AND.X.LE.UP)Y=0
      "GAMMA-CHANGE"=Y
C
C     ("GAMMA-CHECK")
C
      DGAM="COMMAND-GAMMA"
      GW="GAMMA-WEDGES"
      FPA="FPA-SEL-DISPLAY"
      D1=ABS(DGAM-GW)
      D2=ABS(DGAM-FPA)
      GC=1.
      IF(D1.GT.1..OR.D2.GT.1.) GC=-1.
      "GAMMA-CHECK"=GC
C
C     ("GLIDE-SLOPE-CAPTURE")
C
      XOLD=EST(<OLD-GLIDE-SLOPE>)
      GS="GLIDE-SLOPE"
      S=EST(<AIRSPEED-INDICATOR>)*1.688
      AC=EST(<AIRCRAFT-POSITION>)
      XAC=XVALUE(AC)
      YAC=YVALUE(AC)
      WPT="WAYPOINT-5-POSITION"
      XWPT=XVALUE(WPT)
      YWPT=YVALUE(WPT)
      DST=SQRT((XAC-XWPT)**2+(YAC-YWPT)**2)
      DEL=S/(.35*DST)
```

```
      GSC=-1.
      IF(XOLD.GT.0..AND.GS.LE.DEL) GSC=1.
      IF(XOLD.LT.0..AND.GS.GE.-DEL) GSC=1.
      "GLIDE-SLOPE-CAPTURE"=GSC
C
C     ("GS-INT")
C
      XY="AIRCRAFT-POSITION"
      XAC=XVALUE(XY)
      YAC=YVALUE(XY)
      R=ABS(YAC/XAC)
      ANG=ATAN(R)
      GI=1.
      IF(ANG.GT..17) GI=-1.
      IF(STATE(<GLIDE-SLOPE>).EQ.0.) GI=-1.
      "GS-INT"=GI
C
C     ("GS-INTERCEPT")
C
      GS="GLIDE-SLOPE"
      GSI=-1.
      GS=ABS(GS)
      IF(GS.GT..5) GO TO 202
      GSI=1.
      UPPER(<GLIDE-SLOPE>)=.4
      LOWER(<GLIDE-SLOPE>)=-.4
202   CONTINUE
      CRGS=1.1
      IF(GS.LE.1.5) CRGS=1.15
      IF(GS.LE..5) CRGS=1.2
      HOSZC(<GS-INTERCEPT>)=PACKY(HOSZC(<GS-INTERCEPT>),CRGS)
      "GS-INTERCEPT"=GSI
C
C     ("GS-RANGE")
C
      "GS-RANGE"="TD-DISTANCE"
C
C     ("HALF-LOCALIZER")
C
      "HALF-LOCALIZER"="LOCALIZER"/2.
C
C     ("ILS-INT")
C
      XY="AIRCRAFT-POSITION"
      XAC=XVALUE(XY)
      YAC=YVALUE(XY)
      R=ABS(YAC/XAC)
      ANG=ATAN(R)
      XII=1.
      IF(ANG.GT..17) XII=-1.
      "ILS-INT"=XII
```

```
C
C     ("ILS-RANGE")
C
      "ILS-RANGE"="TD-DISTANCE"
C
C     ("INITIAL-GLIDE-SLOPE")
C
      "INITIAL-GLIDE-SLOPE"=EST(<INITIAL-GLIDE-SLOPE>)
C
C     ("INITIAL-GS-LIMITS")
C
      "INITIAL-GS-LIMITS"=EST(<INITIAL-GS-LIMITS>)
C
C     "INITIAL-VALUES"
C
      ISCALE="MAP-SCALES"
      KSCALE=ISCALE-<M1>
      SCALE=(2.**KSCALE)*6076.
      ICRT=<EHSI>
      ISYM1=<WAYPOINT-1-POSITION>
      ISYM2=<WAYPOINT-5-POSITION>
      DO 200 I=ISYM1,ISYM2
      AV=ACTUAL(I)
      XAV=XVALUE(AV)
      YAV=YVALUE(AV)
      CALL SYMPSTN(ICRT,I,I,SCALE,1,XAV,YAV)
200   CONTINUE
      TA="TRACK-BOX"
      ROT=TA-360
      CALL SYMPSTN(ICRT,ISYM1,ISYM2,SCALE,2,ROT,0)
      DESIRE(<MM-INT>)=0.
      DESIRE(<LG-CALL>)=1.
      UPPER(<LG-RANGE>)=45000.
      DESIRE(<LG-RANGE>)=44000.
      LOWER(<LG-RANGE>)=0.
      UPPER(<GS-RANGE>)=80000.
      LOWER(<GS-RANGE>)=0.
      UPPER(<LOC-RANGE>)=80000.
      LOWER(<LOC-RANGE>)=0.
      UPPER(<OM-RANGE>)=38000.
      LOWER(<OM-RANGE>)=32000.
      UPPER(<MM-RANGE>)=7600.
      LOWER(<MM-RANGE>)=4000.
      UPPER(<ILS-RANGE>)=13000.
      LOWER(<ILS-RANGE>)=0.
      DESIRE(<LANDING-SPEED>)=130.
      UPPER(<LANDING-SPEED>)=135.
      LOWER(<LANDING-SPEED>)=120.
```

```
      DESIRE(<LOCALIZER>)=0.
      UPPER(<LOCALIZER>)=.5
      LOWER(<LOCALIZER>)=-.5
      DESIRE(<GLIDE-SLOPE>)=0.
      "INITIAL-VALUES"=0.
C
C     ("LANDING-SPEED")
C
      "LANDING-SPEED"="AIRSPEED-INDICATOR"
C
C     ("LAST-WAYPOINT")
C
      LW="NEXT-WAYPOINT"-1
      LWPT=<WAYPOINT-POSITION>+LW
      NSET1(<REFERENCE-POSITION>)=LWPT
      "LAST-WAYPOINT"=LWPT
C
C     ("LG-CALL")
C
      "LG-CALL"=DESIRE(<LG-CALL>)
C
C     ("LG-RANGE")
C
      "LG-RANGE"="TD-DISTANCE"
C
C     ("LOC-ADJ-BANK")
C
      XLOC="LOCALIZER"
      V10=10.
      "LOC-ADJ-BANK"=SIGN(V10,XLOC)
C
C     ("LOC-ADJ-COMPLETE")
C
      XLOC="LOCALIZER"
      XHALF=EST(<HALF-LOCALIZER>)
      COMP=-1.
      IF(XHALF.GT.0..AND.XLOC.LE.0.)COMP=1.
      IF(XHALF.LT.0..AND.XLOC.GE.0.)COMP=1.
      "LOC-ADJ-COMPLETE"=COMP
C
C     ("LOC-ADJ-FORCE")
C
      XLOC="LOCALIZER"
      V1=1.
      "LOC-ADJ-FORCE"=SIGN(V1,XLOC)
```

```
C
C     ("LOC-ADJ-MIDPOINT")
C
      XLOC="LOCALIZER"
      XHALF=EST(<HALF-LOCALIZER>)*1.3
      XMID=-1.
      IF(XHALF.GT.0..AND.XLOC.LE.XHALF) XMID=1.
      IF(XHALF.LT.0..AND.XLOC.GE.XHALF) XMID=1.
      "LOC-ADJ-MIDPOINT"=XMID
C
C     ("LOC-ADJ-RETURN")
C
      XLOC=EST(<LOC-ADJ-FORCE>)
      "LOC-ADJ-RETURN"=-XLOC
C
C     ("LOC-ADJ-WAIT")
C
      F=DESIRE(<BROLLY-ROLL>)
      D=DESIRE(<ROLL-INDICATOR>)
      R="ROLL-INDICATOR"
      XW=-1.
      IF((D-R)*F.LE.0.) XW=1.
      "LOC-ADJ-WAIT"=XW
C
C     ("LOC-RANGE")
C
      "LOC-RANGE"="TD-DISTANCE"
C
C     ("LOC-RETURN-BANK")
C
      "LOC-RETURN-BANK"=-1.*EST(<LOC-ADJ-BANK>)
C
C     ("MIDDLE-BEACON-MISS")
C
      XLOW=LOWER(<MM-RANGE>)
      DST="TD-DISTANCE"
      XM=1.
      IF(DST.LT.XLOW) XM=-1.
      "MIDDLE-BEACON-MISS"=XM
C
C     ("MM-INT")
C
      "MM-INT"=EST(<MM-INT>)
C
C     ("MM-RANGE")
C
      "MM-RANGE"="TD-DISTANCE"
```

```
C
C     ("NEW-FLAPS")
C
      AS="AIRSPEED-INDICATOR"
      DO 813 I=1,7
      IF(AS.GT.FLPSPD(I)) GO TO 814
813   CONTINUE
      I=8
814   CONTINUE
      IFLP=I-2+<F0  >
      IOFLP=DESIRE(<FLAP-INDICATOR>)+.5
      IF(IFLP.LT.IOFLP) IFLP=IOFLP
      IF(IFLP.GT.IOFLP) IFLP=IOFLP+1
      DESIRE(<FLAP-INDICATOR>)=IFLP
      UPPER(<FLAP-INDICATOR>)=IFLP
      LOWER(<FLAP-INDICATOR>)=IFLP
      CNF=-1.
      IF(IFLP.NE.IOFLP) CNF=1.
      "NEW-FLAPS"=CNF
C
C     ("NEW-MAP-SCALE")
C
      DST="TD-DISTANCE"
      DO 823 I=1,3
      IF(DST.GT.RSTMAP(I)) GO TO 824
823   CONTINUE
      I=4
824   CONTINUE
      IMAP=<M8  >-I+1
      "NEW-MAP-SCALE"=IMAP
C
C     ("OLD-COMMAND-GAMMA")
C
      XGAM=DESIRE(<COMMAND-GAMMA>)
      "OLD-COMMAND-GAMMA"=XGAM
C
C     ("OLD-GLIDE-SLOPE")
C
      "OLD-GLIDE-SLOPE"="GLIDE-SLOPE"
C
C     ("OM-INT")
C
      "OM-INT"=EST(<OM-INT>)
C
C     ("OM-RANGE")
C
      "OM-RANGE"="TD-DISTANCE"
```

```
C
C     ("OUTER-BEACON-MISS")
C
      XLOW=LOWER(<OM-RANGE>)
      DST="TD-DISTANCE"
      XM=1.
      IF(DST.LT.XLOW)XM=-1.
      "OUTER-BEACON-MISS"=XM
C
C     ("RESET-GAMMA")
C
      "RESET-GAMMA"=EST(<OLD-COMMAND-GAMMA>)
C
C     ("REVIEW-MONITORS")
C
      "REVIEW-MONITORS"=0.
C
C     ("ROLL-OUT-FORCE")
C
      F=2.
      R="ROLL-INDICATOR"
      IF(ABS(R).LT.10.) F=1.
      "ROLL-OUT-FORCE"=-SIGN(F,R)
C
C     ("TD-DISTANCE")
C
      AS="AIRCRAFT-POSITION"
      XC=XVALUE(AS)
      YC=YVALUE(AS)
      WPT="WAYPOINT-5-POSITION"
      XWPT=XVALUE(WPT)
      YWPT=YVALUE(WPT)
      D=DIST(XC,YC,0.,XWPT,YWPT,0.)
      "TD-DISTANCE"=D
C
C     ("TRACK-CHECK")
C
      TB="TRACK-BOX"
      TA="TRACK-ANGLE"
      TSD="TRACK-SEL-DISPLAY"
      D1=ABS(TA-TB)
      D2=ABS(TA-TSD)
      TC=1.
      IF(D1.GT.3..OR.D2.GT.3.) TC=-1.
      "TRACK-CHECK"=TC
C
C     ("TRK-CORR-FORCE")
C
      F=EST(<TRK-ERR-TO-WPT>)/10.
      IF(F.GT.2.) F=2.
      IF(F.LT.-2.) F=-2.
      "TRK-CORR-FORCE"=F
```

```
C
C     ("TRK-CORR-STOP")
C
      T=EST(<TRK-TO-WPT>)
      DELTA=180.-T
      TB="TRACK-BOX"
      TE=EST(<TRK-ERR-TO-WPT>)
      TCS=-1.
      SPD=EST(<AIRSPEED-INDICATOR>)*1.688
      RI=ABS("ROLL-INDICATOR")
      TRO=1.+RI/10.
      IF(ABS(RI).LE.10.)TRO=1.+RI/5.
      DTRN=1833.5*TAN(.017*RI)/SPD
      DTRK=TRO+DTRN
      IF(TE.GT.0..AND.TB+DELTA.GT.T+DELTA-DTRK)TCS=1.
      IF(TE.LT.0..AND.TB+DELTA.LT.T+DELTA+DTRK)TCS=1.
      "TRK-CORR-STOP"=TCS
C
C     ("TRK-ERR-TO-WPT")
C
      ANG="TRK-TO-WPT"
      TB="TRACK-BOX"
      DELTA=ANG-TB
      IF(DELTA.LT.-180.) DELTA=360.+DELTA
      IF(DELTA.GT.130.) DELTA=DELTA-360.
      "TRK-ERR-TO-WPT"=DELTA
C
C     ("TRK-TO-WPT")
C
      AC="AIRCRAFT-POSITION"
      WPT="WAYPOINT-POSITION"
      XAC=XVALUE(AC)
      YAC=YVALUE(AC)
      XWPT=YVALUE(WPT)
      YWPT=YVALUE(WPT)
      DST=SQRT((XWPT-XAC)**2+(YWPT-YAC)**2)
      ANG=ACOS((YWPT-YAC)/DST)*57.3
      IF((XWPT-XAC).LT.0.) ANG=360.-ANG
      "TRK-TO-WPT"=ANG
C
C     ("VERT-SPEED-CHECK")
C
      VS="VSI"
      DGAM="COMMAND-GAMMA"*.01745
      AS="AIRSPEED-INDICATOR"*101.3
      VSEST=AS*SIN(DGAM)
      VSC=1.
      IF(ABS(VS-VSEST).GT.50.) VSC=-1.
      "VERT-SPEED-CHECK"=VSC
```

```
C
C     ("WAYPOINT-ALT-CHECK")
C
      ALT="AC-ALTITUDE"
      WA="WAYPOINT-ALTITUDE"
      D="DIST-TO-WAYPOINT"
      S="AIRSPEED-INDICATOR"*1.688
      T=D/S
      VS="VSI"/60.
      ALT=ALT+VS*T
      XRES=1.
      IF(ALT.GT.(1.1*WA).OR.ALT.LT.(.98*WA)) XRES=-1.
      "WAYPOINT-ALT-CHECK"=XRES
C
C     ("WAYPOINT-CLOSE")
C
      NW="NEXT-WAYPOINT"
      WC=2000.
      IF(NW.EQ.5) WC=400.
      "WAYPOINT-CLOSE"=WC
C
C     ("WAYPOINT-GS-CHECK")
C
      GS="GLIDE-SLOPE"
      AGS=ABS(GS)
      XRES=1.
      GTOL=UPPER(<GLIDE-SLOPE>)
      GTOL=GTOL+1.6
      IF(AGS.GT.GTOL) XRES=-1.
      "WAYPOINT-GS-CHECK"=XRES
C
C     ("WAYPOINT-LOC-CHECK")
C
      XLOC="LOCALIZER"
      ALOC=ABS(XLOC)
      XRES=1.
      IF(ALOC.GT.2.) XRES=-1.
      "WAYPOINT-LOC-CHECK"=XRES
C
C     ("WAYPOINT-SPEED-CHECK")
C
      WS="WAYPOINT-SPEED"
      AS="AIRSPEED-INDICATOR"
      XRES=1.
      T=EST(<DIST-TO-WAYPOINT>)/(AS*1.688)
      DIFF=ABS(AS-WS)
      IF(DIFF.GT.(.02*WS).AND.DIFF.GT.T) XRES=-1.
      "WAYPOINT-SPEED-CHECK"=XRES
```

```
HARDWARE FUNCTIONS
      DIMENSION TRNCOS(2,2),TRNRAD(2),CNUX(5),CNUY(5),VSTATE(17)
      REAL KTTOFS,NMTOFT
      DATA CASRAT/1./,ROLLRT/5.0/,G/32./,PI/3.14159/,RDESC/-2./,
     *RASC/.67/,KTTOFS/1.688/,NMTOFT/6076./,SOS/660./
     *,CNUX/-26662.,-33150.,-16774.,-6433.,860./,
     *CNUY/-42064.,-26004.,-5044.,0.,0./
      GO TO 10000
9000  CONTINUE
C
C     ("AUTO-BROLLY-ROLL")
C
      X="XAC   "
      Y="YAC   "
      RI="ROLL-INDICATOR"
      ISEG=0
      IF(X.GE.-6433..AND.Y.GE.-13123.) ISEG=5
      IF(X.LE.-6433..AND.Y.GE.(-.781*X-18149.)) ISEG=4
      IF(X.LE.-6433..AND.Y.LE.(-.781*X-18149.)
     *  .AND.Y.GE.(-.781*X-51906.)) ISEG=3
      IF(X.LE.-25270..AND.Y.LE.(-.781*X-51906.)
     *  .AND.Y.GE.(7.114*X+147615.)) ISEG=2
      IF(Y.LE.AMIN1(-32161.,7.114*X+147615.)) ISEG=1
      IF(ISEG.EQ.0) WRITE(6,8999) X,Y
8999  FORMAT(1X,21HAUTO PATH ERROR--X,Y=,2F10.2)
      IF(ISEG.EQ.2.OR.ISEG.EQ.4) GO TO 220
C     PRESCRIBED PATH IS STRAIGHT OR CURVED PATH IS TO BE
C     INITIATED
210   CONTINUE
      TA="TRACK-BOX"*.017453
      DX=CNUX(ISEG)-X
      DY=CNUY(ISEG)-Y
      RD=SQRT(DX**2+DY**2)
      ANG=ACOS(DY/RD)
      IF(DX.LT.0.) ANG=6.283185-ANG
      ERR=ANG-TA
      AERR=ABS(ERR)
      BR=0.
      IF(AERR.LE..017.AND.RI.LE.-1.)BR=1.
      IF(AERR.LT..017.AND.RI.GE.1.) BR=-1.
      IF(ERR.LT.-.017.AND.RI.GT.-5.) BR=-1.
      IF(ERR.GT..017.AND.RI.LT.5.) BR=1.
      FORCE=2.79*AERR+.05
      IF(ERR.LT..017.AND.RI.GT.1.)FORCE=1.
      IF(ERR.GT.-.017.AND.RI.LT.-1.)FORCE=1.
      FORCE=AMIN1(AMAX1(FORCE,.1),1.)*.6
      BR=BR*FORCE
      IF(ERR.LT.-.017.AND.RI.LT.-5.)ACTUAL(<ROLL-INDICATOR>)=-5.
      IF(ERR.GT..017.AND.RI.GT.5.)ACTUAL(<ROLL-INDICATOR>)=5.
```

```
      GO TO 250
220   CONTINUE
C     PRESCRIBED PATH IS CURVED
      R="CURVED-VECTOR-RADIUS"
      D="CURVED-VECTOR-DIR"
      DIR=0.
C     FIND CENTER OF CURVED-VECTOR CIRCLE(XCTR,YCTR)
      IF(D.EQ.<RIGHT>)DIR=1.
      IF(D.EQ.<LEFT>) DIR=-1.
      DD=0.
      IF(R.GT.1E100) GO TO 210
      DTW=DIST(X,Y,0.,CNWX(ISEG),CNWY(ISEG),0.)
      IF(DTW.LT.500.)GO TO 240
      XCTR=X+DIR*R*COS(TA)
      YCTR=Y-DIR*R*SIN(TA)
C     FIND DISTANCE FROM CIRCLE CENTER TO WAYPOINT(DD)
      DX=CNWX(ISEG)-XCTR
      DY=CNWY(ISEG)-YCTR
      DD=SQRT(DX*DX+DY*DY)
      DD=DD-R
240   CONTINUE
      BR=0.
      DDD=DD*D
      IF(DDD.EQ.0.)GO TO 250
      BR=-SIGN(1.,DDD)
      FORCE=2.79*ATAN(ABS(DD/DTW))+.05
      FORCE=AMIN1(AMAX1(FORCE,.1),1.)+.6
      BR=BR*FORCE
      IF(RI.GT.-30.) GO TO 242
      ACTUAL(<ROLL-INDICATOR>)=-30.
      IF(BR.LT.0.)BR=0.
      GO TO 250
242   IF(RI.LT.30.)GO TO 250
      ACTUAL(<ROLL-INDICATOR>)=30.
      IF(BR.GT.0.)BR=0.
250   CONTINUE
      ACTUAL(<BROLLY-ROLL>)=BR
      "AUTO-BROLLY-ROLL"=BR
C     ("CAS-END")
C
      RATE(<CAS-ENG-DISPLAY>)=0.
      "CAS-END"=0.
C
C     ("CAS-RATE")
C
      T=TFREE(3)-STIME
      IF(T.EQ.0)GO TO 10
      XM=(DESIRE(<CAS-ENG-KNOB>)-"CAS-ENG-KNOB")
      RATE(<CAS-ENG-DISPLAY>)=XM/T
```

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```
 10   CONTINUE
      IF(T.LE.0)RATE(<CAS-ENG-DISPLAY>)=0.
      "CAS-RATE"=0.
C
C     ("COMMAND-GAMMA-RATE")
C
      T=TFREE(4)-STIME
      DES=DESIRE(<COMMAND-GAMMA>)
      ACT="COMMAND-GAMMA"
      R=0.
      IF(T.GT.0.) R=(DES-ACT)/T
      "COMMAND-GAMMA-RATE"=R
C
C     ("NEW-BANK")
C
      PHI=ACTUAL(<ROLL-INDICATOR>)
      APHI=ABS(PHI)
      DPHI="BROLLY-ROLL"*ROLLRT
      IF(ACTUAL(<HOR-PATH-LIGHT>).EQ.<ON>) GO TO 20
      IF(ABS(DPHI).GT..5.OR.APHI.GT.5.) GO TO 20
      DPHI=0.
      ACTUAL(<ROLL-INDICATOR>)=0.
      PHI=0.
20    CONTINUE
      RATE(<ROLL-INDICATOR>)=DPHI
      CTV=<STRAIGHT>
      IF(PHI.GT.0.) CTV=<RIGHT>
      IF(PHI.LT.0.) CTV=<LEFT>
      ACTUAL(<CURVED-VECTOR-DIR>)=CTV
      S="SPEED"*KTTOFS
      R=1E300
      APHI=ABS(PHI)
      IF(APHI.GT.2.) R=S*S/(G*ABS(TAN(PHI*PI/180.)))
      ACTUAL(<CURVED-VECTOR-RADIUS>)=R
      WRITE(6,8002) PHI,DPHI,CTV,R
8002  FORMAT(29HNEW-BANK -- PHI,DPHI,CTV,R = ,4G14.5)
      "NEW-BANK"=PHI
C
C     ("NEW-COMMAND-GAMMA")
C
      SCALE=1.0
      ACTUAL(<COMMAND-GAMMA>)=DESIRE(<COMMAND-GAMMA>)
      "NEW-COMMAND-GAMMA"=0.
C
C     ("NEW-GAMMA")
C
      GAMMA="GAMMA-WEDGES"
      DESGAM="COMMAND-GAMMA"
      DELTA=DESGAM-GAMMA
```

```
      RT=RATE(<GAMMA-WEDGES>)
      DGAM=0.
      IF(DELTA.LT.0.)DGAM=RDESC
      IF(DELTA.GT.0.)DGAM=RASC
      RATE(<GAMMA-WEDGES>)=DGAM
      RATE(<FPA-SEL-DISPLAY>)=DGAM
      IF(DELTA*RT.GT.0.)GO TO 40
      RATE(<GAMMA-WEDGES>)=0.
      RATE(<FPA-SEL-DISPLAY>)=0.
      ACTUAL(<FPA-SEL-DISPLAY>)=DESGAM
      ACTUAL(<GAMMA-WEDGES>)=DESGAM
 40   CONTINUE
      WRITE(6,8004) GAMMA,DGAM
8004  FORMAT(26HNEW-GAMMA -- GAMMA,DGAM = ,2F7.2)
      "NEW-GAMMA"=GAMMA
C
C     ("NEW-LOCATION")
C
      TA="TRACK-BOX"*PI/180.
      S="SPEED"
      PHI="ROLL-INDICATOR"*PI/180.
      DTHETA=G*TAN(PHI)/(S*KTTOFS)
      VSTATE(17)=DTHETA
      DT=STIME-"TACUP"
      THETA=TA+DTHETA*DT
      IF(THETA.GT.2.*PI) THETA=THETA-2.*PI
      IF(THETA.LT.0.) THETA=THETA+2.*PI
      TCHNG=TA-THETA
      ACTUAL(<TRACK-BOX>)=THETA*180./PI
      ACTUAL(<TKA-SEL-DISPLAY>)=THETA*180./PI
      ACTUAL(<TRACK-ANGLE>)=THETA*180./PI
      GAMMA="GAMMA-WEDGES"*PI/180.
      W="WIND-VELOCITY"
      PSI="WIND-DIRECTION"*PI/180.
C     XGS,YGS=X,Y COMPONENTS OF GROUND SPEED
      XGS=S*COS(GAMMA)*SIN(THETA)+W*SIN(PSI)
      YGS=S*COS(GAMMA)*COS(THETA)+W*COS(PSI)
      GS=SQRT(XGS*XGS+YGS*YGS)
      ACTUAL(<GROUND-SPEED>)=GS
      ACTUAL(<GROUND-SPEED-NCDU>)=GS
      ALT="ALTITUDE"
      DALT=S*SIN(GAMMA)*KTTOFS
      RATE(<ALTITUDE>)=DALT
      ACTUAL(<VSI>)=DALT*60.
      DECALT=ACTUAL(<DH-REF-DISPLAY>)
      IF(ALT.LE.DECALT)ACTUAL(<DH-ALTITUDE>)=<ON>
      THOU=IFIX(ALT/1000.)
      ACTUAL(<BARO-ALTIMETER-THOU>)=THOU
      HUN=IFIX(ALT/10.+.5)/10.-IFIX(THOU)*10.
      ACTUAL(<BARO-ALTIMETER-HUND>)=HUN
      X=FLOAT(IFIX(ALT+.5))
```

```
      ACTUAL(<RADIO-ALTITUDE>)=X
      IRA=1
      IF(X.GT.2500.) IRA=0
      STATE(<RADIO-ALTITUDE>)=IRA
      ACTUAL(<ALT-ENG-DISPLAY>)=X
      X="XAC  "
      Y="YAC  "
      IF(PHI.LT.-.017.OR.PHI.GT..017) GO TO 50
C     NON CURVED PATH
      XX=X+DT*XGS*KTTOFS
      YY=Y+DT*YGS*KTTOFS
      GO TO 60
C     CURVED PATH
50    CONTINUE
      SF=S*KTTOFS
      R=SF*SF/(G*TAN(PHI))
      XX=X+R*COS(GAMMA)*COS(THETA)*(1.-COS(DTHETA*DT))
     + +R*SIN(THETA)*SIN(DTHETA*DT)*COS(GAMMA)
      YY=Y-R*COS(GAMMA)*SIN(THETA)*(1.-COS(DTHETA*DT))
     +  +R*COS(THETA)*SIN(DTHETA*DT)*COS(GAMMA)
 60   ACTUAL(<XAC>)=XX
      ACTUAL(<YAC>)=YY
      ACTUAL(<TACUP>)=STIME
      ICRT=<EHSI>
      ACTUAL(ICRT)=PACKXY(XX,YY)
      IAC=<AIRCRAFT-POSITION>
      ACTUAL(IAC)=ACTUAL(ICRT)
      ISYM1=<WAYPOINT-1-POSITION>
      ISYM2=<WAYPOINT-5-POSITION>
      ISCALE="MAP-SCALES"
      KSCALE=ISCALE-<M1>
      SCALE=(2.**KSCALE)*6076.
      DO 70 I=ISYM1,ISYM2
      AV=ACTUAL(I)
      XAV=XVALUE(AV)
      YAV=YVALUE(AV)
      CALL SYMPSTN(ICRT,I,I,SCALE,1,XAV,YAV)
70    CONTINUE
      ROT="TRACK-BOX"-360.
      CALL SYMPSTN(ICRT,ISYM1,ISYM2,SCALE,2,ROT,0)
      WRITE(6,8005) XX,YY,DT,THETA,DTHETA,ALT,DALT,R
8005  FORMAT(41HNEW-LOCATION -- XX,YY,DT,THETA,DTHETA,ALT,
     +  10H,DALT,R = /2F10.1,3F7.3,2F8.2,G14.5)
      XOM=ABS(XX+34269.)
      YM=ABS(YY)
      XMM=ABS(XX+3580.)
      ACTUAL(<OUTER-BEACON-LIGHT>)=<OFF>
      IF(XOM.LT.1000..AND.YM.LT.3000.)
     +  ACTUAL(<OUTER-BEACON-LIGHT>)=<ON>
```


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```
      ACTUAL(<MIDDLE-BEACON-LIGHT>)=<OFF>
      IF(XMM.LT.750..AND.YM.LT.2000.)
     +  ACTUAL(<MIDDLE-BEACON-LIGHT>)=<ON>
      IF(XX.GT.1000.)CALL ENDPT(999)
      "NEW-LOCATION"=1.
C
C     ("NEW-SPEED")
C
      S="SPEED"
      DES="CAS-ENG-DISPLAY"
      DS=CASRAT
      IF(S.GT.DES) DS=-CASRAT
      IF(S.EQ.DES) DS=0.
      ACTUAL(<FLIGHT-PATH-ACC>)=DS*60.
      RATE(<SPEED>)=DS
      ACTUAL(<AIRSPEED-INDICATOR>)=S
      ACTUAL(<MACH-INDICATOR>)=S/SOS
      WRITE(6,8001) S,DS
8001  FORMAT(20HNEW-SPEED -- S,DS = ,2G14.5)
      "NEW-SPEED"=S
C
C     ("PATH-ERRORS")
C
      AC="AIRCRAFT-POSITION"
      XAC=XVALUE(AC)
      YAC=YVALUE(AC)
      ZAC="ALTITUDE"
      ICLTK="CRUISE-LAND-TST-KNOB"
      IF(ICLTK.EQ.<LAND>) GO TO 170
C     USE MLS MODE ERRORS
      NW="NEXT-WAYPOINT"
      INW=<WAYPOINT-POSITION>+NW
      WPTP=ACTUAL(INW)
      XB=XVALUE(WPTP)
      YB=YVALUE(WPTP)
      ZB="WAYPOINT-ALTITUDE"
      IF(NW.EQ.1) GO TO 110
      ILW=INW-1
      WPTP=ACTUAL(ILW)
      XA=XVALUE(WPTP)
      YA=YVALUE(WPTP)
      ZA=ACTUAL(<WAYPOINT-ALTITUDE>+NW-1)
      GO TO 120
110   CONTINUE
      XA=-170.
      YA=-45787.
      ZA=4902.
120   CONTINUE
      IF(NW.EQ.2.OR.NW.EQ.4) GO TO 160
```

```
C     DESIRED PATH IS STRAIGHT LINE
C     XA,YA,ZA IS LAST WAYPOINT
C     XB,YB,ZB IS NEXT WAYPOINT
C     DETERMINT PROPORTION OF ARC LENGTH (Q) FROM A TO B
C     THAT DEFINES PATH POINT CLOSEST TO AIRCRAFT
      DXAB=XB-XA
      DYAB=YB-YA
      DZAB=ZB-ZA
      DXAAC=XAC-XA
      DYAAC=YAC-YA
      DZAAC=ZAC-ZA
      QNUM=DXAAC*DXAB+DYAAC*DYAB+DZAAC*DZAB
      QDEM=DXAB*DXAB+DYAB*DYAB+DZAB*DZAB
      Q=QNUM/QDEM
C     DETERMINE PATH-POINT CLOSEST TO AIRCRAFT XP,YP,ZP
      XP=XA+Q*DXAB
      YP=YA+Q*DYAB
      ZP=ZA+Q*DZAB
C     DETERMINE GLIDESLOPE ERROR (EGS) WITH 1 DOT=100 FT.
      EGS=(ZP-ZAC)/100.
C     DETERMINE MAGNITUDE OF LOCALIZER ERROR (ELOCM) WITH
C     1 DOT=500 FT.
      DLX=XAC-XP
      DLY=YAC-YP
      ELOCM=SQRT(DLX*DLX+DLY*DLY)/500.
C     DETERMINE DIRECTION OF LOCALIZER ERROR (ELOCD)
C     WITH RIGHT=-1.,LEFT=+1.
C     XR,YR IS ON LINE PERPENDICULAR TO PATH AT XP,YP
C     XR=XP+DX AND YR=YP+DY
C     AND UNIT DISTANCE TO RIGHT OF XP,YP
C     THETA IS DESIRED TRACK ANGLE
      DST=SQRT(QDEM)
      THETA=ACOS(DYAB/DST)
      IF(DXAB.LT.0.) THETA=2.*PI-THETA
      DX=+SIN((PI/2.)-THETA)
      DY=-COS((PI/2.)-THETA)
      ONE=1.
      IF(ABS(DY).GT.ABS(DX)) GO TO 130
      ELOCD=-SIGN(ONE,(XAC-XP)*DX)
      GO TO 140
130   CONTINUE
      ELOCD=-SIGN(ONE,(YAC-YP)*DY)
140   CONTINUE
      ELOC=ELOCD*ELOCM
      GO TO 180
160   CONTINUE
C     DESIRED PATH IS CIRCULAR ARC
C     COMPARE AIRCRAFT LOCATION TO DESIRED TURN
C     CENTER (XCTR,YCTR) AND DESIRED TURN
C     RADIUS (DTR) TO DETERMINE LOCALIZER ERROR
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```
      XCTR=-25270.23
      YCTR=-32161.02
      DTR=10000.3
      ALTA=3500
      ALTB=2402
      ATURN=2.094
      IF(NW.EQ.2) GO TO 165
      XCTR=-6432.86
      YCTR=-13123.09
      DTR=13123.09
      ALTA=1002
      ALTB=384
      ATURN=.908
165   CONTINUE
      DX=XAC-XCTR
      DY=YAC-YCTR
      D=SQRT(DX*DX+DY*DY)
      ELOC=(D-DTR)/500.
C     DETERMINE PROPORTION OF ARC LENGTH (Q) FROM A TO B
C     INTERCEPTED BY LINE FROM TURN CENTER TO AIRCRAFT
      DX=XA-XCTR
      DY=YA-YCTR
      DCTRA=SQRT(DX*DX+DY*DY)
      DX=XAC-XCTR
      DY=YAC-YCTR
      DCTRAC=SQRT(DX*DX+DY*DY)
      DX=XAC-XA
      DY=YAC-YA
      DAB=SQRT(DX*DX+DY*DY)
      DNUM=DCTRA*DCTRA+DCTRAC*DCTRAC-DAB*DAB
      DDEN=2.*DCTRA*DCTRAC
      ANG=ACOS(DNUM/DDEN)
      Q=ANG/ATURN
C     DETERMINE DESIRED ALTITUDE (DESALT) AS PROPORTION Q
C     BETWEEN ALTITUDE AT A (ALTA) AND ALTITUDE
C     AT B (ALTB)
      DESALT=ALTA+Q*(ALTB-ALTA)
      EGS=(DESALT-ZAC)/100.
      GO TO 180
170   CONTINUE
C     USE ILS MODE ERRORS
C     LOCALIZER ANTENNA IS AT X=12425,Y=0,Z=0
C     GLIDESLOPE ANTENNA IS AT X=1000,Y=500,Z=0
C     EACH LOCALIZER DOT IS 1 DEGREE
C     EACH GLIDESLOPE DOT IS .35 DEGREE
      XL=12425.
      XGS=1000.
      YGS=500.
      ELOC=ATAN(YAC/(XL-XAC))*57.3
```

```
      DX=XGS-XAC
      DY=YGS-YAC
      GD=SQRT(DX*DX+DY*DY)
      EGS=(3.-ATAN(ZAC/GD)*57.3)/.35
180   CONTINUE
C     SET ACTUAL VALUES OF INSTRUMENTS TO
C     CALCULATED ERRORS
      ACTUAL(<LOCALIZER>)=ELOC
      ACTUAL(<GLIDE-SLOPE>)=EGS
      VSTATE(1)="BROLLY-PITCH"
      VSTATE(2)="BROLLY-ROLL"
      ITHR="THROTTLE-LEVER"
      VSTATE(3)=2.
      IF(ITHR.EQ.<IDLE>)VSTATE(3)=1.
      VSTATE(4)=0.
      VSTATE(5)="ALTITUDE"
      VSTATE(6)=EGS
      VSTATE(7)=ELOC
      VSTATE(8)="AIRSPEED-INDICATOR"
      VSTATE(9)=RATE(<ALTITUDE>)
      VSTATE(10)="XAC  "
      VSTATE(11)="YAC  "
      VSTATE(12)="GAMMA-WEDGES"
      VSTATE(13)="ROLL-INDICATOR"
      VSTATE(14)="TRACK-BOX"
      VSTATE(15)=RATE(<COMMAND-GAMMA>)
      VSTATE(16)=RATE(<ROLL-INDICATOR>)
      CALL LPTAPE(3,VSTATE,DUMMY)
      WRITE(6,8003) ELOC,EGS,XAC,YAC,ZAC,XA,YA,ZA,XB,YB,ZB,NW
8003  FORMAT(44HPATH-ERRORS -- ELOC,EGS,XAC,YAC,ZAC,XA,YA,ZA,
     +  15H,XB,YB,ZB,NW = /2X,2F7.2,9F10.1,I3)
      "PATH-ERRORS"=PACKXY(ELOC,EGS)
C
C     ("SYMBOL-SCALE")
C
      MS=DESIRE(<MAP-SCALES>)
      MSO="MAP-SCALE"
      ICHNG=MSO-MS
      SCLCNG=2.**ICHNG
      ICRT=<EHSI>
      ISYM1=<WAYPOINT-1-POSITION>
      ISYM2=<WAYPOINT-5-POSITION>
      CALL SYMPSTN(ICRT,ISYM1,ISYM2,SCALE,3,SCLCNG,0.)
      ACTUAL(<MAP-SCALE>)=MS
      ACTUAL(<MAP-SCALES>)=MS
      "SYMBOL-SCALE"=MS
```

```
HARDWARE PROCEDURES
      DEFINE THE PROCEDURE AC-UPDATE.
                IF HOR-PATH-LIGHT IS ON THEN COMPUTE AUTO-BROLLY-ROLL.
                COMPUTE NEW-SPEED,NEW-BANK,
                NEW-GAMMA,NEW-LOCATION,PATH-ERRORS.
      DEFINE THE PROCEDURE TO SIMULATE BROLLY-PITCH.
START:          SET RATE OF COMMAND-GAMMA TO COMMAND-GAMMA-RATE.
END:            COMPUTE NEW-COMMAND-GAMMA.
                SET RATE OF COMMAND-GAMMA TO 0 DEGREES.
      DEFINE THE PROCEDURE TO SIMULATE CAS-ENG-KNOB.
START:          COMPUTE CAS-RATE.
END:            COMPUTE CAS-END.
      DEFINE THE PROCEDURE TO SIMULATE MAP-SCALES.
END:            COMPUTE SYMBOL-SCALE.
      DEFINE THE PROCEDURE TO SIMULATE START-SIMULATION.
START:          START AC-UPDATE.
      DEFINE THE PROCEDURE TO SIMULATE VEL-CWS-SWITCH.
END:            SET HOR•ATH-LIGHT TO OFF.
                SET VERT-PATH-LIGHT TO OFF.
                SET VEL-CWS-LIGHT TO ON.
OPERATOR PROCEDURES
      DEFINE THE PROCEDURE TO MONITOR AIRSPEED-CHECK.
                COMPUTE AIRSPEED-CHECK.
                IF RESULT IS LESS THAN 0 THEN NOTIFY-ATC.
                IF NEW-FLAPS IS GREATER THAN 0
                THEN COMPUTE CALL-FLAPS.
                END.
      DEFINE THE PROCEDURE TO MONITOR ALTITUDE-CHECK.
                IF RADIO-ALTITUDE IS ACTIVE THEN READ
                RADIO-ALTITUDE.
                COMPUTE ALTITUDE-CHECK.
                IF RESULT IS LESS THAN 0 THEN NOTIFY-ATC.
                END.
      DEFINE THE PROCEDURE TO APPROACH-WAYPOINT.
                IF WAYPOINT-SPEED-CHECK IS LESS THAN 0
                THEN NOTIFY-ATC.
                IF WAYPOINT-ALT-CHECK IS LESS THAN 0
                THEN NOTIFY-ATC.
                IF WAYPOINT-GS-CHECK IS LESS THAN 0
                THEN NOTIFY-ATC.
                IF WAYPOINT-LOC-CHECK IS LESS THAN
                0 THEN NOTIFY-ATC.
                IF HOR-PATH-LIGHT IS ON THEN END.
                IF TURN-TO-WAYPOINT IS ACTIVE THEN
                  ROLL-OUT AND END TURN-TO-WAYPOINT.
                SET CRITICALITY OF BROLLY-ROLL TO 1.
                SET CRITICALITY OF ROLL-INDICATOR TO 1.
                IF ROLL-INDICATOR IS GREATER THAN 5 DEGREES OR
                IF IT IS LESS THAN -5 DEGREES THEN ROLL-OUT.
      DEFINE THE PROCEDURE TO ADJUST BROLLY-ROLL.
                IF BROLLY-CONTROL IS GREATER THAN 0 THEN WAIT.
```

```
START:          COMPUTE DESIRED-CURVATURE.
                COMPUTE DELTA-CURVATURE.
                IF BROLLY-STOP IS NOT GREATER THAN 0 THEN GO TO START
                NOW.
                ALTER BROLLY-ROLL TO 0.
      DEFINE THE PROCEDURE TO ADJUST THE CAS-ENG-DISPLAY.
                IF THE CAS-ENG-DISPLAY IS OK THEN END.
                SET THE CAS-ENG-KNOB TO CAS-CHANGE.
      DEFINE THE PROCEDURE TO MONITOR CALL-FLAPS.
                IF FLAP-INDICATOR IS NOT OK THEN
                COMPUTE CALL-FLAPS.
                END.
      DEFINE THE PROCEDURE TO ADJUST THE COMMAND-GAMMA.
                IF GAMMA-CHANGE IS OK THEN END.
                IF VEL-CWS-LIGHT IS OFF THEN DEPRESS VEL-CWS-SWITCH.
                GRASP LEFT-BROLLY-HANDLE.
                GRASP RIGHT-BROLLY-HANDLE.
                ALTER BROLLY-PITCH TO THE RESULT.
                IF BROLLY-CONTROL IS GREATER THAN 0 THEN WAIT.
                ALTER BROLLY-PITCH TO 0.
      DEFINE THE PROCEDURE TO ADJUST DH-ALTITUDE.
START:          COMPUTE DH-CRIT.
                IF DH-ALTITUDE IS OFF AND IF RADIO-ALTITUDE
                IS GREATER THAN 180 FEET THEN GO TO START.
                IF DH-CONDITION IS LESS THAN 0
                THEN PERFORM MISSED-APPROACH.
      DEFINE THE PROCEDURE TO ADJUST FLARE-COND.
START:          COMPUTE FLARE-CRIT.
                IF RADIO-ALTITUDE IS GREATER THAN 65 FEET
                THEN ADJUST STRAIGHT-VECTOR AND ADJUST LOCALIZER AND
                   GO TO START.
                PULL THROTTLE-LEVER TO IDLE.
                ALTER COMMAND-GAMMA TO 0 DEGREES.
                END PROCEDURE &COMMAND-GAMMA.
                ALTER BROLLY-PITCH TO 5.
                IF GAMMA-WEDGES IS LESS THAN 0 DEGREES
                THEN WAIT.
                ALTER BROLLY-PITCH TO 0.
      DEFINE THE PROCEDURE TO FLY-TO-WAYPOINT.
                DESIGNATE NEXT-WAYPOINT AS WAYPOINT OF INTEREST.
                COMPUTE COURSE-CHANGE.
                IF RESULT IS NOT 0
                THEN BEGIN TURN-TO-WAYPOINT.
                IF RESULT IS 0 THEN MONITOR STRAIGHT-VECTOR.
                ALTER CAS-ENG-DISPLAY TO WAYPOINT-SPEED.
CRIT:           ALTER CRITICALITY OF FLY-TO-WAYPOINT TO
                  FLY-TO-CRIT.
                IF DIST-TO-WAYPOINT IS GREATER THAN
                WAYPOINT-CLOSE THEN GO TO CRIT.
                SET CRITICALITY OF FLY-TO-WAYPOINT TO 1.5.
                IF WAYPOINT-NAME IS NOT GPIUL THEN
```

```
        APPROACH-WAYPOINT.
      END MONITORING STRAIGHT-VECTOR.
      SET CRITICALITY OF STRAIGHT-VECTOR TO 1.5.
      IF ST-VECT-BEING-ADJ IS LESS THAN 0
        THEN END.
      ROLL-OUT.
      LET ST-VECT-BEING-ADJ BE -1.
      END.
DEFINE THE PROCEDURE TO MONITOR GAMMA-CHECK.
      COMPUTE GAMMA-CHECK.
      IF RESULT IS LESS THAN 0 THEN NOTIFY-ATC.
      END.
DEFINE PROCEDURE TO MONITOR GLIDE-SLOPE.
      ALTER CRITICALITY OF FLY-TO-WAYPOINT TO
        FLY-TO-CRIT.
      IF GLIDE-SLOPE IS OK THEN WAIT.
      IF VEL-CUS-LIGHT IS OFF THEN DEPRESS VEL-CUS-SWITCH.
      IF RADIO-ALTITUDE IS LESS THAN 100 FEET
      THEN END.
      SET CRITICALITY OF COMMAND-GAMMA TO 1.8.
      COMPUTE OLD-COMMAND-GAMMA.
      COMPUTE OLD-GLIDE-SLOPE.
      SET COMMAND-GAMMA TO GAMMA-ADJ-PITCH.
      ADJUST COMMAND-GAMMA.
      ADJUST GLIDE-SLOPE-CAPTURE.
      SET COMMAND-GAMMA TO RESET-GAMMA.
      ADJUST COMMAND-GAMMA.
      SET CRITICALITY OF COMMAND-GAMMA TO 1.
DEFINE PROCEDURE TO ADJUST GLIDE-SLOPE-CAPTURE.
      IF GLIDE-SLOPE-CAPTURE IS LESS THAN 0 THEN WAIT.
      END.
DEFINE THE PROCEDURE TO ADJUST GS-INTERCEPT.
      IF GS-INTERCEPT IS LESS THAN 0 THEN WAIT.
      ALTER COMMAND-GAMMA TO -3 DEGREES.
      ADJUST COMMAND-GAMMA.
      MONITOR GLIDE-SLOPE.
      END.
DEFINE PROCEDURE TO MONITOR LOCALIZER.
      ALTER CRITICALITY OF FLY-TO-WAYPOINT TO
        FLY-TO-CRIT.
      IF LOCALIZER IS OK THEN WAIT.
      IF TURN-TO-WAYPOINT IS ACTIVE THEN END.
      IF VEL-CUS-LIGHT IS OFF THEN DEPRESS VEL-CUS-SWITCH.
      IF ST-VECT-BEING-ADJ IS GREATER THAN 0 THEN END.
      LET LOC-BEING-ADJUSTED BE 1.
      COMPUTE HALF-LOCALIZER.
      TURN BROLLY-ROLL TO LOC-ADJ-FORCE.
      SET ROLL-INDICATOR TO LOC-ADJ-BANK.
      ADJUST ROLL-INDICATOR.
      ALTER BROLLY-ROLL TO 0.
      IF LOC-ADJ-MIDPOINT IS LESS THAN 0 THEN WAIT.
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                ALTER BROLLY-ROLL TO LOC-ADJ-RETURN.
                SET ROLL-INDICATOR TO LOC-RETURN-BANK.
                ADJUST ROLL-INDICATOR.
                IF LOC-ADJ-COMPLETE IS LESS THAN 0
                  THEN WAIT.
                ROLL-OUT.
                LET LOC-BEING-ADJUSTED BE -1.
                END.
      DEFINE THE PROCEDURE TO MONITOR MAP-SCALE.
                IF MAP-SCALE IS NOT EQUAL TO
                NEW-MAP-SCALE THEN TURN
                MAP-SCALES TO NEW-MAP-SCALE.
                END.
      DEFINE THE PROCEDURE TO MONITOR MIDDLE-BEACON-LIGHT.
START:          IF MIDDLE-BEACON-LIGHT IS ON THEN GO TO STOP.
                IF MIDDLE-BEACON-MISS IS GREATER THAN 0
                THEN GO TO START.
                NOTIFY-ATC.
STOP:           ALTER LIMITS OF LOCALIZER TO .2.
                ALTER LIMITS OF GLIDE-SLOPE TO .2.
                END.
      DEFINE THE PROCEDURE MISSED-APPROACH.
                END.
      DEFINE THE MISSION.
                COMPUTE FIRST-WAYPOINT.
                DESIGNATE NEXT-WAYPOINT AS WAYPOINT OF INTEREST.
                TURN START-SIMULATION TO ON.
                COMPUTE INITIAL-VALUES.
                SET LIMITS OF GLIDE-SLOPE TO INITIAL-GS-LIMITS.
                ALTER COMMAND-GAMMA TO INITIAL-GLIDE-SLOPE.
                LET LOC-BEING-ADJUSTED BE -1.
                LET ST-VECT-BEING-ADJ BE -1.
                SET LIMITS OF COMMAND-GAMMA TO .1.
                SET LIMITS OF GAMMA-CHANGE TO .1.
                MONITOR COMMAND-GAMMA,CAS-ENG-DISPLAY.
                MONITOR AIRSPEED-CHECK,GAMMA-CHECK,
                ALTITUDE-CHECK,VERT-SPEED-CHECK,TRACK-CHECK,
                REVIEW-MONITORS,CALL-FLAPS,MAP-SCALE.
NEXT:           FLY-TO-WAYPOINT.
                MILESTONE 1.
                IF WAYPOINT-NAME IS GPIUL THEN END.
                IF WAYPOINT-NAME IS NOT DUBIL THEN GO TO
                  ADD1 NOW.
                ALTER LIMITS OF GLIDE-SLOPE TO .2.
                ALTER LIMITS OF LOCALIZER TO .2.
                IF VEL-CWS-LIGHT IS OFF
                  THEN DEPRESS VEL-CWS-SWITCH.
ADD1:            ADD 1 TO  NEXT-WAYPOINT.
                GO TO NEXT NOW.
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      DEFINE THE PROCEDURE TO NOTIFY-ATC.
                END.
      DEFINE THE PROCEDURE TO MONITOR OUTER-BEACON-LIGHT.
START:          IF OUTER-BEACON-LIGHT IS ON THEN GO TO STOP.
                IF OUTER-BEACON-MISS IS GREATER THAN 0
                THEN GO TO START.
                NOTIFY-ATC.
STOP:           ADJUST GS-INTERCEPT.
                END.
      DEFINE THE PROCEDURE TO MONITOR REVIEW-MONITORS.
                ALTER CRITICALITY OF FLY-TO-WAYPOINT
                  TO FLY-TO-CRIT.
                IF GS-INT IS GREATER THAN 0 AND IF GS-RANGE IS OK
                THEN MONITOR GLIDE-SLOPE,LOCALIZER.
                IF OM-INT IS GREATER THAN 0 AND IF OM-RANGE IS OK
                THEN ADJUST OUTER-BEACON-LIGHT.
                IF MM-INT IS GREATER THAN 0 AND IF MM-RANGE IS OK
                THEN ADJUST MIDDLE-BEACON-LIGHT. ,
                IF LG-CALL IS NOT GREATER THAN 0 OR IF LG-RANGE IS NOT OK
                THEN GO TO SKIP NOW.
                COMPUTE CALL-LANDING-GEAR.
                COMPUTE CALL-CHECKLIST-FLAPS.
                PULL SPEED-BRAKE-LEVER TO ON.
SKIP:           IF WAYPOINT-NAME IS GPIUL THEN
                  ADJUST DH-ALTITUDE,FLARE-COND.
                IF CRUISE-LAND-TST-KNOB IS CRUISE AND IF ILS-INT IS
                GREATER THAN 2 AND IF ILS-RANGE IS OK THEN COMPUTE
                CALL-LAND-MODE.
                END.
      DEFINE THE PROCEDURE TO ADJUST ROLL-INDICATOR.
START:          COMPUTE LOC-ADJ-WAIT.
                IF RESULT IS LESS THAN 0 THEN GO TO START NOW.
                END.
      DEFINE THE PROCEDURE TO ROLL-OUT.
                ALTER CRITICALITY OF ROLL-INDICATOR TO 5.
                ALTER BROLLY-ROLL TO ROLL-OUT-FORCE.
                ALTER ROLL-INDICATOR TO 0 DEGREES.
                ADJUST ROLL-INDICATOR.
                ALTER BROLLY-ROLL TO 0.
      DEFINE THE PROCEDURE TO MONITOR THE STRAIGHT-VECTOR.
START:          LET TOLERANCE BE 2.
                ALTER CRITICALITY OF FLY-TO-WAYPOINT TO
                  FLY-TO-CRIT.
                IF HOR-PATH-LIGHT IS ON AND IF DIST-PAST-WAYPOINT
                  IS LESS THAN 1500 THEN LET TOLERANCE BE 20.
                IF ABS-TRK-ERR-TO-WPT IS LESS THAN TOLERANCE THEN END.
                IF VEL-CWS-LIGHT IS OFF THEN DEPRESS VEL-CWS-SWITCH.
                IF LOC-BEING-ADJUSTED IS GREATER THAN 0 THEN END.
                IF LOCALIZER IS NOT OK AND IF CRUISE-LAND-TST-KNOB
                   IS LAND THEN END.
                LET ST-VECT-BEING-ADJ BE 1.
                ALTER BROLLY-ROLL TO TRK-CORR-FORCE.
```

```
                ALTER CRITICALITY OF STRAIGHT-VECTOR TO 2.2.
CYCLE:          IF ROLL-INDICATOR IS GREATER THAN
                15 DEGREES OR IF IT IS LESS
                THAN -15 DEGREES THEN ALTER
                BROLLY-ROLL TO 0.
                IF TRK-CORR-STOP IS LESS THAN 0
                THEN GO TO CYCLE NOW.
                ROLL-OUT.
                ALTER CRITICALITY OF STRAIGHT-VECTOR TO 1.5.
STOP:           LET ST-VECT-BEING-ADJ BE -1.
                END.
     DEFINE THE PROCEDURE TO MONITOR TRACK-CHECK.
                COMPUTE TRACK-CHECK.
                IF RESULT IS LESS THAN 0 THEN NOTIFY-ATC.
                END.
     DEFINE THE PROCEDURE TO TURN-TO-WAYPOINT.
AUTO:           IF VEL-CWS-LIGHT IS ON THEN GO TO MANUAL NOW.
                LET TOLERANCE BE 50000.
                IF DIST-PAST-WAYPOINT IS GREATER THAN 1500 THEN
                  LET TOLERANCE BE AUTO-CURVE-TOL.
                IF ABS-DIST-WPT-TO-CRV IS GREATER THAN TOLERANCE THEN
                  GO TO ENDAUT NOW.
                IF ROLL-INDICATOR IS GREATER THAN 30 DEGREES OR IF IT
                  IS LESS THAN -30 DEGREES THEN GO TO ENDAUT NOW.
                IF DIST-TO-WAYPOINT IS LESS THAN WAYPOINT-CLOSE THEN END.
                GO TO AUTO.
ENDAUT:         DEPRESS VEL-CWS-SWITCH.
MANUAL:         ALTER CRITICALITY OF BROLLY-ROLL TO 1.8.
                IF ROLL-INDICATOR IS GREATER THAN 5 DEGREES
                OR IF IT IS LESS THAN -5 DEGREES
                THEN GO TO CYCLE NOW.
                SET BROLLY-ROLL TO COURSE-CHANGE.
                ADJUST BROLLY-ROLL.
CYCLE:          IF ABS-DIST-WPT-TO-CRV IS LESS THAN CURVE-TOL
                THEN GO TO STOP NOW.
                SET CRITICALITY OF ROLL-INDICATOR TO 2.
                ALTER ROLL-INDICATOR TO ROLL-INDICATOR.
                ALTER ROLL-INDICATOR BY CURVED-ADJ-BANK.
                ALTER BROLLY-ROLL TO CURVED-ADJ-FORCE.
                ADJUST ROLL-INDICATOR.
                ALTER BROLLY-ROLL TO 0.
                IF BROLLY-CONTROL IS GREATER THAN 0 THEN WAIT.
                GO TO CYCLE.
STOP:           SET CRITICALITY OF BROLLY-ROLL TO 1.
                SET CRITICALITY OF ROLL-INDICATOR TO 1.8.
                SET CRITICALITY OF FLY-TO-WAYPOINT TO 1.5.
                IF DIST-TO-WAYPOINT IS GREATER THAN
                WAYPOINT-CLOSE THEN GO TO CYCLE.
                END.
     DEFINE THE PROCEDURE TO MONITOR VERT-SPEED-CHECK.
                COMPUTE VERT-SPEED-CHECK.
                IF RESULT IS LESS THAN 0 THEN NOTIFY-ATC.
                END.
```

APPENDIX B
SIMULATION INPUT DATA

B. SIMULATION INPUT DATA

This appendix describes the input parameter values used in the HOS TCV simulation. Preceding each set of parameters is a brief description of the significance of each. All crewstation dimensions and locations shown are in centimeters and are referenced to the center of the EADI, as indicated in the HOS data deck by the METRIC card. The three numbers on the METRIC card indicated the location of the EADI relative to the operator's design eye reference point. The coordinate system is a right-handed, three-dimensional frame with the plus X axis to the operator's right, the plus Y axis directly to the front of the operator, and the plus Z axis directly upward.

B.1 DISPLAY, CONTROL, AND SYMBOL SECTIONS

Figures B-1 through B-3 present the input parameters for the devices in the Display, Control, and Symbol sections for the scenario employing the curved approach and the VCWS control mode. In order to implement the other simulation scenarios it is necessary to change the last one or two parameters (initial values) for several devices. These changes are listed in Figure B-4. The indicated value in Figure B-4 should appear as the eighth parameter on the data record or the eighth and ninth parameters where two parameters (coordinate values) are indicated. The interpretation of each parameter is as follows:

Parameter	Interpretation
1. Model Number	Number referencing model specifications section.
2. Initial Hab Strength	Number between Ø and 1.
3. Initial State	Ø = Inactive, 1 = Active
4. Initial Criticality	Positive real number representing relative priority of device for monitoring and adjusting operations.

5.	X Coordinate	Measured in cm relative to reference point on METRIC card.
6.	Y Coordinate	Measured in cm relative to reference point on METRIC card.
7.	Z Coordinate	Measured in cm relative to reference point on METRIC card.
8.	Initial Value	Numerical value or coordinate pair.

B.2 OPERATOR FUNCTIONS

Figure B-5 lists the input parameters for the Operator Functions for the simulation scenario employing the curved approach and the VCWS control mode. Variations in initial values for other scenarios are indicated in Figure B-6. The indicated value in Figure B-6 should appear as the sixth parameter on the data record. The interpretation of each parameter is as follows:

Parameter		Interpretation
1.	Function Type	Indication of function type with respect to numerical value restriction and relevance of recall and extrapolation operations: 0 = Real, extrapolatable, recallable 1 = Integer, extrapolatable, recallable 2 = Real, not extrapolatable, recallable 3 = Integer, not extrapolatable, recallable 4 = Real, extrapolatable, not recallable 5 = Integer, extrapolatable, not recallable 6 = Real, not extrapolatable, not recallable 7 = Integer, not extrapolatable, not recallable
2.	Initial Hab Strength	Number between Ø and 1.
3.	Initial State	Ø = Inactive, 1 = Active.
4.	Initial Criticality	Positive real number.
5.	Computation Time	Positive real number representing time in seconds to compute function.
6.	Initial Value	Numerical value.

B.3 PROCEDURE SECTION

Figure B-7 lists the initial criticalities for each operator procedure. Procedures not shown are assigned a default criticality of one.

B.4 MODEL SPECIFICATIONS

Figure B-8 lists the model specification parameters. The interpretation of each of these parameters is as follows for displays, controls, and symbols:

	Parameter	Interpretation
1.	Number of Parameters	Number from 1 - 8 (1 - 9 for controls).
2.	Body Part Required to Absorb/Manipulate	1 = eyes, 2 = eyes or hands, 3 = hands, 4 = feet.
3.	Absorption/Manipulation Accuracy	For continuous and positional devices, the standard deviation to be used in sampling estimated values on absorptions and in determining actual values on control manipulations. If the number is negative, then it is interpreted as a (positive) fraction of the actual value of the device; otherwise it represents absolute units for the device. For both absorptions and manipulations, sampling is from a normal distribution with mean equal to the actual value of the device. This parameter is not used (though an entry is required) for discrete devices.
4.	Micro-Absorb Time Charge	Positive real number representing time in seconds for a single cycle in the absorption process.
5.	Device Width	Measured in cm.
6.	Model Type	Indication of model type with respect to numerical value restriction and relevance of recall and extrapolation operations: 0 = Real, extrapolatable, recallable 1 = Integer, extrapolatable, recallable 2 = Real, not extrapolatable, recallable 3 = Integer, not extrapolatable, not recallable 4 = Real, extrapolatable, not recallable 5 = Integer, extrapolatable, not recallable 6 = Real, not extrapolatable, not recallable 7 = Integer, not extrapolatable not recallable
7.	Lower Limit	Lower value limit of device.
8.	Upper Limit	Upper value limit of device.

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Parameter	Interpretation
9. F	For rotary controls, F is the force required to turn the control. For non-rotaty controls, F is the rate of change during a manipulation in units per second.
10. Control Type	Indicates whether the control is rotary (1) or not (Ø).

For integrated CRT displays:

Parameter	Interpretation
1. Number of Parameters	Number from 1 to 10.
2. Body Part Required to Absorb	1 = eyes, 2 = eyes or hands, 3 = hands, 4 = feet.
3. Absorption Accuracy	The standard deviation to be used in sampling the estimated coordinate values represented by the center of the CRT screen. If the number is negative then it is interpreted as a (positive) fraction of the actual coordinate values associated with the screen center; otherwise it represents absolute units for the coordinate dimensions. Sampling is from a normal distribution with mean equal to the actual coordinate value.
4. Screen Width	Measured in cm.
5. Screen Height	Measured in cm.
6. X Coordinate (Reference Point)	Horizontal distance in cm from lower-left corner of screen to CRT center reference point.
7. Y Coordinate (Reference Point)	Vertical distance in cm from lower-left corner of screen to CRT center reference point.
8. X Coordinate (Normal Vector)	For a vector normal to the plane of the screen.
9. Y Coordinate (Normal Vector)	For a vector normal to the plane of the screen.
10. Z Coordinate (Normal Vector)	For a vector normal to the plane of the screen.

B.5 HUMAN OPERATOR SPECIFICATIONS

Figure B-9 lists the characteristics of the operator. The interpretation of each of these parameters is as follows:

Parameter	Interpretation
1. X Coordinate	Initial fixation coordinate measured in cm.
2. Y Coordinate	Initial fixation coordinate measured in cm.
3. Z Coordinate	Initial fixation coordinate measured in cm.
4. Eye Fixation Tolerance	Maximum lateral distance (measured in cm) from the operator's eye fixation point at which an object will still be assumed to be fixated.
5. Extended Arm Length	Measured in cm.
6. Extended Leg Length	Measured in cm.

Operator's hands, feet, shoulders, and hips:

Parameter	Interpretation
1. X Coordinate	Initial (and relaxed) body part location (right).
2. Y Coordinate	Initial (and relaxed) body part location (right).
3. Z Coordinate	Initial (and relaxed) body part location (right).
4. X Coordinate	Initial (and relaxed) body part location (left).
5. Y Coordinate	Initial (and relaxed) body part location (left).
6. Z Coordinate	Initial (and relaxed) body part location (left).

B.6 RUN PARAMETERS

The RUN PARAMETERS card (Figure B-10) initializes certain simulation parameters. The interpretation of these parameters is as follows:

	Parameter	Interpretation
1.	REMEM	The time cost of a memory recall attempt.
2.	SURE	The value to which the hab strength must be incremented before an absorption or an operator function calculation can be completed.
3.	SMALL	The simulation standard for a small number (used in a variety of ways).
4.	EXFAC	In calculation of time costs for operator functions, EXFAC is the factor by which the time cost for recall of component variables is multiplied to account for "plugging in" and other mental juggling of variables.
5.	THRESH	Numerical value between 0 and 1 used to determine whether or not a recall attempt is successful.
6.	HABFAC	The factor for the degradation of hab strength over time.
7.	HABTOL	Tolerance value used when a device value is being absorbed to determine when hab strength is sufficiently near an asympotic value to terminate the cyclic absorption process.
8.	TINC	Maximum acceptable waiting time used in decision on procedure interruptions and swapping of body part assignments.
9.	TDIF	A time standard used to determine if the simulation will wait for a body part presently in use to become available or switch body part assignments.
10.	TRELAX	A time standard used to determine if an unoccupied body part will be moved to its relaxed position.

11.	HABCY	The upper limit on the number of cycles allowed for incrementing hab strength in absorption and operator function computations.
12.	REMCY	The upper limit on the number of cycles allowed for a recall attempt.
13.	HABTIM	The maximum time allowed for incrementing hab strength on an absorption or operator function calculation.
14.	REMTIM	The maximum time allowed for a recall attempt.

```
SYSTEM                  TEST-----TCV
METRIC                  0 45.6 -34.5

DISPLAY SECTION
EADI                    34 0 1 1.0 0 0 0 0 0
ROLL INDICATOR          14 0 1 1.8 0 1.58 3.38 0
LOCALIZER               15 0 1 1. 0 -1.81 -3.87 0
GLIDE SLOPE             15 0 1 1. -4.9 -.168 -.36 0
RADIO ALTITUDE          12 0 0 1.0 4.2 1.09 2.34 -1
AIRCRAFT PITCH          23 0 1 1.0 0 0 0 ON
DH ALTITUDE             7 0 1 1.4 0 0 0 OFF
GAMMA WEDGES            25 0 1 1.0 0 0 0 0
COMMAND GAMMA           26 0 1 1. 0 0 0 0
FLIGHT PATH ACC         27 0 1 1.0 0 0 0 0
HORIZON                 24 0 1 1.0 0 0 0 ON
PITCH REF LINE          26 0 1 1.0 0 -.396 -.846 -3
RUNWAY LINE INTRCPT     28 0 1 1.0 0 0 0 0
RUNWAY LINE ANGLE       31 0 1 1.0 0 0 0 0
TRACK POINTER           28 0 1 1.0 0 0 0 0
DH REF DISPLAY          12 0 1 1.0 51.3 -23.4 -27.3 188
PITCH REF DISPLAY       12 0 1 1.0 57.7 -23.4 -27.3 -3
EHSI                    35 0 1 1.0 0 -13.5 -17.2 -170 -45787
TRACK BOX               29 0 1 1.0 0 -6.29 -11.16 280
TRACK BUG               30 0 1 1.0 0 -6.91 -11.67 02
STRAIGHT VECTOR         24 0 1 1.5 0 -13.8 -17.45 ON
CURVED VECTOR RADIUS    28 0 1 1.0 0 -13.8 -17.45 ON
CURVED VECTOR DIR       22 0 1 1.0 0 -13.8 -17.45 STRAIGHT
MAP SCALE               11 0 1 1.0 -5.7 -20.01 -22.65 M4
GROUND SPEED            10 0 1 1.0 4.7 -20.01 -22.65 ON
WIND DIRECTION          10 0 1 1.0 4.1 -20.54 -23.1 0
WIND VELOCITY           10 0 1 1.0 4.1 -20.54 -23.1 0
BARO ALTIMETER THOU     1 0 1 1.0 17.2 .29 .62 4.9
BARO ALTIMETER HUND     2 0 1 1.0 17.2 .29 .62 .02
VSI                     4 0 1 1. 17.2 -3.9 -8.37 0
MACH INDICATOR          10 0 1 1.0 -14.1 .88 1.9 .35
AIRSPEED INDICATOR      3 0 1 1.0 -14.1 .88 1.9 210.
OUTER BEACON LIGHT      7 0 1 1.2 27.6 .59 1.26 OFF
MIDDLE BEACON LIGHT     7 0 1 1.2 27.6 .59 1.26 OFF
CAS ENG DISPLAY         12 0 1 1.2 47.1 0 26.3 210.
ALT ENG DISPLAY         12 0 1 1.0 54.3 0 26.3 4902
FPA SEL DISPLAY         12 0 1 1.0 61.1 0 26.3 -3.
TKA SEL DISPLAY         12 0 1 1.0 67.6 0 26.3 280
VEL CWS LIGHT           7 0 1 1.0 48.9 0 17.8 ON
AUTO LIGHT              7 0 1 1.0 53.9 0 17.8 OFF
HOR PATH LIGHT          7 0 1 1.0 60.1 0 17.8 OFF
VERT PATH LIGHT         7 0 1 1.0 53.6 0 17.8 OFF
SPEED BRAKES ARMED      7 0 1 1.0 33.1 -2.61 -5.58 OFF
FLAP INDICATOR          5 0 1 1.0 68.3 3.62 7.74 F1
```

Figure B-1. Display Section

```
DONT ARM SB ANN         7 0 1 1.0 33.1 -2.02 -4.32 ON
LANDING GEAR ANN        7 0 1 1.0 74.5 2.91 6.21 OFF
CAS ENG LIGHT           7 0 1 1.0 49.3 0 21.9 ON
ALT ENG LIGHT           7 0 1 1.0 55.7 0 21.9 OFF
FPA SEL LIGHT           7 0 1 1.0 62.6 0 21.9 OFF
TKA SEL LIGHT           7 0 1 1.0 69.4 0 21.9 OFF
NCDU                    33 0 1 1.0 0 -28.1 -26.4 0 0
ALTITUDE NCDU           10 0 1 1.0 3.0 -25.49 -25.7 4902
ALTITUDE ERROR          10 0 1 1.0 3.0 -26.74 -26.03 0
FLIGHT PATH ERROR       10 0 1 1.0 3.0 -27.71 -26.29 0
TRACK ANGLE             10 0 1 1. -3.0 -28.48 -26.5 280
TRACK ANGLE ERROR       10 0 1 1.0 -3.0 -29.45 -26.76 02
TRK ERR DIRECTION       16 0 1 1.0 -3.0 -29.45 -26.76 LEFT
CROSS TRACK ERROR       10 0 1 1.0 -3.0 -30.7 -27.09 0
CR TRK ERR DIRECT       16 0 1 1.0 -3.0 -30.7 -27.09 LEFT
GROUND SPEED NCDU       10 0 1 1.0 3.0 -29.45 -26.76 210
SPEED                   32 0 0 1.0 0 0 0 210.
XAC                     32 0 0 1.0 0 0 0 -170
YAC                     32 0 0 1.0 0 0 0 -45787
ALTITUDE                32 0 0 1.0 0 0 0 4902
TACUP                   32 0 0 1.0 0 0 0 0
```

Figure B-1. Display Section (continued)

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```
CONTROL SECTION
WPT ALT                 6 0 1 1.0 35.1 -23.69 -27.45 OFF
TREND VECTOR            6 0 1 1.0 37.1 -23.69 -27.45 OFF
MAP SCALES              9 0  1 1.0 42.3 -23.86 -27.55 M4
TRACK UP SWITCH         8 0 1 1.0 42.3 -20.05 -25.35 TRACK
VEL CWS SWITCH          6 0 1 1.0 48.9 0 17.8 ON
AUTO SWITCH             6 0 1 1.0 53.9 0 17.8 OFF
HOR PATH SWITCH         6 0 1 1.0 60.1 0 17.8 OFF
VERT PATH SWITCH        6 0 1 1.0 62.2 0 17.8 OFF
BROLLY PITCH            17 0 1 1.0 -17.5 -10.4 -1.1 0
BROLLY ROLL             17 0 1 1.0 -17.5 -10.4 -1.1 0
LEFT BROLLY HANDLE      18 0 1 1.0 -17.5 -10.4 -1.1 0
RIGHT BROLLY HANDLE     18 0 1 1.0 17.5 -10.4 -1.1 0
CAS·ENG KNOB            13 0 1 1.0 46.2 0 21.9 0
ALT ENG KNOB            13 0 1 1.0 52.5 0 21.9 0
FPA SEL KNOB            13 0 1 1.0 54.5 0 21.9 0
TKA SEL KNOB            13 0 1 1.0 66.2 0 21.9 0
DH REF KNOB             13 0 1 1.0 51.3 -26.0 -28.8 0
PITCH REF KNOB          13 0 1 1.0 55.5 -26.0 -28.8 0
AUTO MANUAL LIGHT       7 0 1 1.0 59.5 -26.0 -28.8 MANUAL
CRUISE LAND TST KNOB    8 0 1 1.0 57.7 -20.3 -25.5 CRUISE
AUTO MANUAL SWITCH      6 0 1 1.0 59.5 -26.0 -28.8 OFF
SPEED BRAKE LEVER       19 0 1 1.0 44.8 -20.5 -7.0 OFF
THROTTLE LEVER          19 0 1 1.0 53.1 -22.5 -8.0 ON
START SIMULATION        36 0 1 1. -17.5 -10.4 -1.1 OFF
```

Figure B-2. Control Section

```
SYMBOL SECTION
AIRCRAFT SYMBOL        20 0 1 1.0 0 -13.5 -17.2 OH
AIRCRAFT POSITION      20 0 1 1.0 0 -13.5 -17.2 -16774 -5044
WAYPOINT 1 NAME        20 0 1 1.0 .003 -11.359 -15.402 QUARY
WAYPOINT 2 NAME        20 0 1 1.0 -1.567 -10.668 -14.823 RAPID
WAYPOINT 3 NAME        20 0 1 1.0 -3.975 -11.73 -15.714 NORMA
WAYPOINT 4 NAME        20 0 1 1.0 -4.646 -12.494 -16.357 DUBIL
WAYPOINT 5 NAME        20 0 1 1.0 -4.737 -13.071 -16.842 GPIUL
WAYPOINT 1 ALTITUDE    20 0 1 1.0 .003 -11.359 -15.402 3500
WAYPOINT 2 ALTITUDE    20 0 1 1.0 -1.567 -10.668 -14.823 2402
WAYPOINT 3 ALTITUDE    20 0 1 1.0 -3.975 -11.73 -15.714 1002
WAYPOINT 4 ALTITUDE    20 0 1 1.0 -4.646 -12.494 -16.357 384
WAYPOINT 5 ALTITUDE    20 0 1 1.0 -4.737 -13.071 -16.842 0
WAYPOINT 1 SPEED       20 0 1 1.0 .003 -11.359 -15.402 185
WAYPOINT 2 SPEED       20 0 1 1.0 -1.567 -10.668 -14.823 160
WAYPOINT 3 SPEED       20 0 1 1.0 -3.975 -11.73 -15.714 140
WAYPOINT 4 SPEED       20 0 1 1.0 -4.646 -12.494 -16.357 130
WAYPOINT 5 SPEED       20 0 1 1.0 -4.737 -13.071 -16.842 [illegible]
WAYPOINT 1 POSITION    21 0 1 1.0 .003 -11.359 -15.402 -26662 -42064
WAYPOINT 2 POSITION    21 0 1 1.0 -1.567 -10.668 -14.823 -33150 -26004
WAYPOINT 3 POSITION    21 0 1 1.0 -3.975 -11.73 -15.714 -16774 -5044
WAYPOINT 4 POSITION    21 0 1 1.0 -4.646 -12.494 -16.357 -6433 0
WAYPOINT 5 POSITION    21 0 1 1.0 -4.737 -13.071 -16.842 860 0
OUTER MARKER NAME      20 0 1 1.0 0 -13.5 -17.2 OM
OUTR MKR POSITION      20 0 1 1.0 0  -13.5 -17.2 0 0
MIDDLE MARKER NAME     20 0 1 1.0 0 -13.5 -17.2 MM
MID MKR POSITION       20 0 1 1.0 0 -13.5 -17.2 0 0
RUNWAY 1000FT MARK     22 0 1 1.0 0 0 0 00
RNWY 1000FT POSITION   21 0 1 1.0 0 0 0 0 0
```

Figure B-3. Symbol Section

Device	SCENARIO Curved VCWS	Curved 3D-Auto	Straight-in VCWS
(Displays)			
EHSI	-170,-45787	-170,-45787	-65631,0
TRACK BOX	280	278	92
TRACK BUG	2	0	2
BARO ALTIMETER THOU	4.9	4.9	1.5
BARO ALTIMETER HUND	.02	.02	.1
ALT ENG DISPLAY	4902	4902	1510
TKA SEL DISPLAY	280	278	92
VEL CWS LIGHT	ON	OFF	ON
AUTO LIGHT	OFF	ON	OFF
HOR PATH LIGHT	OFF	ON	OFF
VERT PATH LIGHT	OFF	ON	OFF
ALTITUDE NCDU	4902	4902	1510
TRACK ANGLE	280	278	92
TRACK ANGLE ERROR	2	0	2
XAC	-170	-170	-65631
YAC	-45787	-45787	0
ALTITUDE	4902	4902	1510
(Controls)			
VEL CWS SWITCH	ON	OFF	ON
AUTO SWITCH	OFF	ON	OFF
HOR PATH SWITCH	OFF	ON	OFF
VERT PATH SWITCH	OFF	ON	OFF
AUTO MANUAL LIGHT	MANUAL	AUTO	MANUAL
(Symbols)			
AIRCRAFT POSITION	-170,-45787	-170,-45787	-65631,0
WAYPOINT 1 ALTITUDE	3500	3500	1510
WAYPOINT 2 ALTITUDE	2402	2402	1510
WAYPOINT 1 POSITION	-26662,-42064	-26662,-42064	-55084,0
WAYPOINT 2 POSITION	-33150,-26004	-33150,-26004	-44536,0
WAYPOINT 3 POSITION	-16774,-5044	-16774,-5044	-17938,0

Figure B-4. Variations in Initial Values for Displays, Controls, and Symbols for Different Simulation Scenarios

```
OPERATOR FUNCTIONS
DESIRED CURVATURE      6 0 1 1. .01 0
DELTA CURVATURE        6 0 1 1. .01 0
BROLLY STOP            6 0 1 1. .01 0
DIST WPT TO CURVE      6 0 1 1. .02 0
INITIAL VALUES         6 0 1 1. 0. 0
GAMMA CHANGE           6 0 1 1.0 .04 0
CAS CHANGE             6 0 1 1.0 .02 0
AC ALTITUDE            6 0 1 1. .1 0
AIRSPEED CHECK         6 0 1 1. .1 0
GAMMA CHECK            6 0 1 1. .1 0
ALTITUDE CHECK         6 0 1 1. .1 0
VERT SPEED CHECK       6 0 1 1. .1 0
TRACK CHECK            6 0 1 1. .1 0
REVIEW MONITORS        6 0 1 1.1 .1 0
CALL LANDING GEAR      6 0 1 1.0 .1 0
CALL CHECKLIST FLAPS   6 0 1 1.0 .1 0
FLARE COND             6 0 1 1.4 .1 0
CALL LAND MODE         6 0 1 1.0 .1 0
COURSE CHANGE          6 0 1 1. .02 0
GS INT                 6 0 1 .5 .1 0
GS RANGE               6 0 1 .5 .1 0
TD DISTANCE            6 0 1 .5 .1 0
LOC RANGE              6 0 1 .5 .1 0
OM INT                 6 0 1 .5 .1 -1.
OM RANGE               6 0 1 .5 .1 0
MM INT                 6 0 1 .5 .1 1.
MM RANGE               6 0 1 .5 .1 0
LG CALL                6 0 1 .5 .1 0
LG RANGE               6 0 1 .5 .1 0
ILS INT                6 0 1 .5 .1 0
ILS RANGE              6 0 1 .5 .1 0
DIST TO WAYPOINT       6 0 1 .5 .1 0
WAYPOINT CLOSE         6 0 1 .5 .1 0
BROLLY CONTROL         6 0 1 1. .05 0
CURVED ADJ BANK        6 0 1 .5 .05 0
CURVED ADJ FORCE       6 0 1 .5 .05 0
LOC ADJ FORCE          6 0 1 .5 .02 0
LOC ADJ BANK           6 0 1 .5 .02 0
LOC ADJ WAIT           6 0 1 .5 .02 0
OLD COMMAND GAMMA      6 0 1 .5 .02 0
LOC ADJ RETURN         6 0 1 .5 .02 0
GAMMA ADJ PITCH        6 0 1 .5 .02 0
WAYPOINT SPEED CHECK   6 0 1 .5 .02 0
WAYPOINT ALT CHECK     6 0 1 .5 .02 0
WAYPOINT GS CHECK      6 0 1 .5 .02 0
WAYPOINT LOC CHECK     6 0 1 .5 .02 0
LANDING SPEED          6 0 1 1. .05 210.
```

Figure B-5. Operator Functions

```
OUTER BEACON MISS      6 0 1 1. .05 1.
MIDDLE BEACON MISS     6 0 1 1. .05 1.
NEW FLAPS              6 0 1 1. .1 -1.
CALL FLAPS             6 0 1 1. .1 4
NEW MAP SCALE          7 0 1 1. .1 15
ABS TRK ERR TO WPT     6 0 1 1. .1 0
DIST PAST WAYPOINT     6 0 1 1. .01 0
LAST WAYPOINT          6 0 1 1. .01 0
ROLL OUT FORCE         6 0 1 1. .02 0.
TRK TO WPT             6 0 1 1. .02 0.
TRK ERR TO WPT         6 0 1 1. .01 0.
TRK CORR FORCE         6 0 1 1. .05 0.
TRK CORR STOP          6 0 1 1. .1 0.
RESET GAMMA            6 0 1 .5 .02 0
CURVE TOL              6 0 1 1. 0. 0.
AUTO CURVE TOL         6 0 1 1. 0. 0.
ABS DIST WPT TO CRV    6 0 1 1. 0. 0.
GS INTERCEPT           6 0 1 1. 0. 0.
GLIDE SLOPE CAPTURE    6 0 1 2.0 .01 0
HALF LOCALIZER         6 0 1 1. .01 0
LOC ADJ COMPLETE       6 0 1 1. .01 0
LOC ADJ MIDPOINT       6 0 1 1. .01 0
LOC RETURN BANK        6 0 1 1. .01 0
OLD GLIDE SLOPE        6 0 1 1. .01 0
FLY TO CRIT            6 0 1 1. .01 0
INITIAL GLIDE SLOPE    6 0 1 1. 0. -3.
INITIAL GS LIMITS      6 0 1 1. 0. .4
FIRST WAYPOINT         6 0 1 1. 0. 1.
DH CONDITION           6 0 1 1. 0. 1.
FLARE CRIT             6 0 1 1. 0. 1.
DH CRIT                6 0 1 1. 0. 1.
```

Figure B-5. Operator Functions (continued)

Function	Curved VCWS	Curved 3D-Auto	Straight-in VCWS
OM INT	-1	-1	1
INITIAL GLIDE SLOPE	-3	-3	0
INITIAL GS LIMITS	4	1	10

Figure B-6. Variations in Initial Values for Operators Functions for Different Simulations Scenarios.

PROCEDURE SECTION	
TURN TO WAYPOINT	1.5
NOTIFY ATC	5.
APPROACH WAYPOINT	2.
ROLL OUT	3.
MISSED APPROACH	5.

Figure B-7 Procedure Section

```
MODEL SPECIFICATIONS
1.BARO ALT THOU        5 1 0 .04 7.4 5
2.BARO ALT HUND        5 1 .03 .04 7.4 4
3.AIRSPEED IND         5 1 .5 .04 7.4 5
4.VSI                  5 1 .03 .04 7.4 5
5.FLAP IND             5 1 0 .04 4.3 7
6.MOMENTARY SWT        7 2 0 0 2.16 7 0 .1
7.SMALL LITE           5 1 0 .01 2.16 7
8.DISCRETE CONT        7 2 0 .02 2.6 7 0 .1
9.DISCRETE CONT6       7 2 0 .04 1.4 7 0 .1
10.WRITTEN DISP        5 1 0 .04 .54 4
11.CONT WRIT DISP      5 1 0 .03 .54 7
12.DIGITAL DISP        5 1 0 .04 .9 4
13.CONT KNOBS          9 2 0 0 1.9 6 -720 720 85 1
14.ROLL IND            7 1 0 .04 .84 4 50 50
15.SMALL SCALES        7 1 .03 .04 5.42 4 6 6
16.TWO SETTING         5 1 0 .02 .54 7
17.BROLLY PANDR        9 3 .05 .01 7 4 -10 10 10 0
18.BROLLY HANDLES      9 3 0 0 7 4 -10 10 10 0
19.CONTROL STAND       7 3 0 .02 7 7 0 1.5
20.SYMBOLS 1           5 1 0  .04 .54 7
21.SYMBOLS 2           5 1 0 .04 .54 4
22.RUNWAY VECTOR       5 1 0 .02 2.54 7
23.AIRCRAFT PITCH      5 1 .5 .06 2.54 4
24.SMALL SYMBOLS       5 1 0  .02 2.54 7
25.GAMMA WEDGES        5 1 .03 .03 2.9 6
26.COMMAND GAMMA       5 1 0  .03 2.9 4
27.FLIGHT PATH ACC     5 1 4 .03 4.78 4
28.RUNWY LINE INT      5 1 1 .03 1 4
29.TRACK BOX           5 1 0 .03 .54 5
30.TRACK BUG           5 1 1 .06 .54 4
31.RUNWY LIN ANG       5 1 5 .04 .54 4
32.STATE V             5 1 0 0 0 6
33.NCDU                10 1 0 0 11.6 8.7 5.8 4.35 0. -.259 .966
34.EADI                10 1 0 0 17.6 12.7 8.8 6.35 0. -.906 .423
35.EHSI                10 1 0 0 14.8 20.1 7.4  5.7 0. -.643 .766
36.START SIMULATION    7 2 0 0 7 7 0 .01
END OF MODEL SPEX
```

Figure B-8. Model Specifications

```
HUMAN OPERATOR SPEX
EYES                    0 0 0 .5 96 122
HANDS                   17.5 -10.4 -1.1 -17.5 -10.4 -1.1
FEET                    15.2 .1 -84.9 -15.2 .1 -84.9
SHOULDERS               15.2 -45.6 19.3 -15.2 -45.6 19.3
HIPS                    15.2 -45.6 -39.2 -15.2 -45.6 -39.2
END OF HUMAN SPEX
```

Figure B-9. Human Operator Specifications

```
RUN PARAMETERS      .12 .7 .01 2. .2 1. .01 5. 5. .5 10. 10. .5 .5
```

Figure B-10. Run Parameters

APPENDIX C

STANDARD TO SI UNITS CONVERSION

C. STANDARD TO SI UNITS CONVERSION TABLE

To Convert From	To	Multiply By
Feet	Meters	.3048
Knots	Kilometers/hour	8.573
Knots	Meters/second	.5144
Inches	Centimeters	2.540

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15 Supplementary Notes

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The requirement for the use of the International System of Units (SI) as the primary unit of measure has been waived for this report.

16 Abstract

A generic operator model called HOS has been used to simulate the behavior and performance of a pilot flying a transport airplane during instrument approach and landing operations. The study was conducted to demonstrate the applicability of the model to problems associated with interfacing a crew with a flight system. The model has been installed and operated on NASA Langley's central computing system. This document presents a description of the model itself and the preliminary results of its application to an investigation of an innovative display system under development in Langley's Terminal Configured Vehicle Program.

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